UNITED STATES NAVY
AVIATION MECHANICS' TRAINING SYSTEM

—FOR—

Engine Maintenance Force
STANDARD SCHOOLS

Course Manual
—FOR—
MACHINIST'S MATES' (A) (ADVANCED) COURSE

Chas. E. Lucke

COURSE MANUAL

FOR

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UNITED STATES NAVY AVIATION MECHANICS' TRAINING SYSTEM

FOR

ENGINE MAINTENANCE FORCE

COURSE MANUAL

FOR

Machinist's Mates' (A) (Advanced) Course

PREPARED AND ISSUED BY

UNITED STATES NAVY GAS ENGINE SCHOOL

COLUMBIA UNIVERSITY, NEW YORK, N. Y.

LIEUT. COMDR. CHARLES E. LUCKE, DIRECTOR

AND

UNITED STATES NAVAL TRAINING STATION

GREAT LAKES, ILL.

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The following is a list of texts which have been utilized or quoted in the preparation of this volume:

"Internal Combustion Engines," by Judge.

"Aero Engines," by Burls.

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"Lessons in Practical Electricity," by Swoope.

"Aviation Engines," by Pagé.

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"Kerosene versus Gasoline in Standard Automobile Engines," by Lucke.

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CHAPTER I

PRELIMINARY WORK

School Rules, Regulations

1. Lecture by Supervising Instructor.—The supervising instructor shall give an hour's talk on the rules and regulations of the school as follows:

The class hours of the school are 9:00 A.M. to 12:00 M. and 1:30 to 5:30 P.M. daily, with study period aboard the *U. S. Granite State* from 8:00 to 10:00 P.M. Lectures will be given from 9:00 to 11:00 A.M. and from 1:30 to 3:30 P.M. Study periods will be from 11:00 A.M. to 12 M. and from 3:30 to 4:30 P.M. A quiz on the subjects covered in the lectures of the day is given daily from 4:30 to 5:30 P.M. Two hours of study, from 8:00 to 10:00 P.M., are required of each student every week-day evening except Saturday. An instructor will be assigned to the ship to assist the class in its study work and he will call the roll at 8:00 P.M. Any student who can show to the instructor that his work is completed and satisfactory, may be excused from that evening's study period at the discretion of the instructor.

The supervising instructor, or his assistant, will assign a definite classroom seat to each student and will appoint a class leader who will be responsible for the class rolls and for the discipline of the class. The class leader will muster the class at 9:00 A.M., 1:30 P.M., and 5:30 P.M., and will report all absentees and tardiness to the office of the supervising instructor. Any student who is absent from classes, due to sickness while ashore on liberty, will immediately get into communication with the office of the supervising instructor, who will have the Navy doctor attend the patient.

Liberty from classes is granted only by the Officer-in-Charge of the station, via the supervising instructor. Liberty from the ship is granted on all Saturday evenings until Monday morning and on Wednesday evenings of the third, fourth and fifth weeks of the course. No student (officers excepted) is allowed to live ashore during the course unless he has the written permission of the medical officer of the *U. S. S. Granite State.* Liberty from the ship on study evenings is granted only when approved by the supervising instructor.

Only men of higher than ordinary caliber are selected for this course and naturally it is expected that there will be no occasion for disciplinary action. The class leader is held responsible for the conduct of the class and for the cleanliness of the classroom. Captain's inspection is held every Saturday morning.

Students completing the course appear before the rating board and are recommended for the rating for which they qualify. In rating, many factors are taken into consideration, such as age, education, personality, executive ability and experience, foreman ability, persistence under difficulty, grades attained during the course, previous gas-engine experience, shop experience and success for age and opportunities.

Occasionally students in being transferred from the stations find discrepancies in their pay accounts. They will consult the Administrative Ensign in such cases.

Following this preliminary lecture, an inspection will be made of all identification disks, and a report will be made of all men who have not had vaccination, prophylactic inoculation or finger prints.

Men desiring to draw small stores will see the Administrative Ensign.

Mail addressed to students should be marked with the aviation class number and addressed in care of the U. S. Navy Gas Engine School, Columbia University, New York City.

Besides this talk on school rules, the preliminary work will include filling out of the student record cards, taking of individual photographs for student record cards, preliminary examination, lecture on Machinist's Mates' (A) Training System and a lecture on the engineering duties at Naval air stations. This preliminary work requires two days.

Filling out Student Record Cards

2. Instructions and Explanation.—On pages 116 and 177 in the syllabus is shown a copy of the form which is to be filled out by every student. On this card are added the grades obtained by the student during the course and the recommendations of the rating board. The original copy of this record card is kept permanently on file at the school, a copy is sent to the Bureau of Navigation and a copy is put in the student's service record. The following directions are emphasized for the attainment of uniformity:

Give your *full* name, putting your last name first, then your first name and finally your middle name; for example, Smith, John Henry.

For class number, give the official number of your aviation class in this school.

Do not write on the line marked *graduating.*

Under *old rating* put your present rating, the rating at which you are actually paid.

Cross out U.S.N. or U.S.N.R.F., the one which does not apply to you. If you are in the Reserve Force, fill in the class of service in which you are enrolled.

Do not write on the lines marked *new rating* or *summary of special fitness*.

Under *position held* list the more important positions you have held, mentioning name of firm, kind of business, position held, class of work, approximate date of commencing position and date of finishing, number of men directly in your charge, and mention salary you received on your last two jobs.

Under *education* mention name of school or college, mention date of graduation, degree obtained and course taken.

Under *date of enlistment* give date for present war. If continuous service, give date of first enlistment. If your past military experience has been in the Army, mention details.

Under *practical experience* cross out the work that has not been done. Give length of time of each line of experience, and if you have served apprenticeship, make special note of it, with date.

Photographs

3. Individual Photographs of Students.—Individual photographs, 1¼ in. by 1¼ in., are taken of each student by the school photographer. These pictures are pasted on the student record cards.

Preliminary Examination

4. Twelve Questions. A twelve-question examination is given (time allowed, 3½ hr.). Six of these questions cover theory, five on gas-engine principles and one on ignition. Six of the questions cover practical work, three on gas-engine operation and three on shop practice.

Machinist's Mates' (A) Training System

5. Lecture by Supervising Instructor. Each student is furnished with a copy of the syllabus covering the Aviation Mechanics' training system. The supervising instructor reads pp. 14 to 19 and 25 to 27, covering the organization and course of instruction of the Machinist's Mates' (A) School. Then, pp. 68 to 77 on Pelham Bay Training Station are covered. Next, pp. 136 to 142 on the Aviation Engineer Officer's course are read and explained. This is followed by reading and explaining of pp. 184 to 190 relative to the U. S. Navy Liberty Motor School. Following this explanation of the training system, the class spends about two hours on further study of the syllabus.

Operating program of Naval air stations has not been fully standardized to date. The outline given on pp. 6 to 8 of the syllabus gives an idea of the classes of work done and the handling of work orders.

Duties at Naval Air Station

6. Operating Program, Qualifications. Work on aircraft engines is divided into two classes at air stations. The *outside work,* constituting all minor jobs on the engines, is done by the squadron, beach and hangar working parties. These groups make the minor adjustments, replacements and repairs, and also remove damaged engines from the planes and install the overhauled engines. The outside work is under the direction of the squadron commander.

The *inside work* is under the direction of the Engineer Officer. This work is done in the shops and includes major adjustments, repairs and replacements.

Engineer's Duties, Qualifications. All inside work on engines and all engineering duties on the air station come under the jurisdiction of the Engineer Officer. Compared with a civilian organization, the Engineer Officer's duties are similar to those of a factory manager. It is the object of the course of instruction at the Aviation Engineer Officer's school to train officers and men to fill all engineering duties on an air station.

Graduates of this school recommended for the rank of Ensign are qualified for the duties of Engineer Officers. At some stations the Engineer Officer is in charge of the overhauling and testing of engines, machine shop, the copper shop, the electrical shop; of the generation of power, heat and light for the entire station; the pumping station and garage; and also supervises all experimental work and the erection of new buildings. It is evident that the Engineer Officer should have previous gas-engine experience, and be of mature age and possess sound judgment. He should have had much executive experience, and it is desirable that he possess a technical training and a knowledge of machine-shop practice. The Engineer Officer's representative in the shop is known as the shop superintendent who, in most cases, holds the rank of Warrant Machinist. This officer has charge of the engine assembly shop, the bench work, the machine shop, engine testing, smith shop and the electrical shop. It is essential that this officer be a qualified machinist and have experience as a machine-shop executive, preferably in the gas-engine line.

The assembly shop has a Chief Machinist's Mate in charge as foreman. He usually has 24 engine assemblers and helpers. The size of this group depends on the size of the station, the above-mentioned number being typical for a one-squadron station. It is essential that the foreman shall have served in the assembly of gas engines and that he can handle men. Bench work has a Chief Machinist's Mate as foreman, with four assistants. The machine shop has a Chief Machinist's Mate in charge as foreman with the necessary machine hands as assistants. The foreman must have served as a machinist and must be able to handle men.

The smith shop rates a Coppersmith as foreman with whatever assistants that are necessary. A Chief Machinist's Mate is in charge of

the engine test stands. It is desirable that he has had previous experience in testing gasoline engines, such experience as that obtained on the test stands of an automobile factory. The electrical shop has a Chief Electrician or a Chief Machinist's Mate in charge. It is desirable for this foreman to have previous experience with gas engines and with different types of ignition systems, also to be able to handle such electrical repairs as may be found necessary on the equipment. As an assistant, the Engineer Officer has a Warrant Machinist. The qualifications for this position are almost the same as those for Engineer Officer except that the officer may be younger and have less executive experience.

One Chief Machinist's Mate on the Engineer Officer's staff has the title of Motor Statistician. His duties are to keep a detailed log of all engines, noting the time of operation before all adjustments, repairs and replacements are necessary. From this data, it is possible to know just when attention must be given to the various engine parts. Information thus obtained may lead to an improvement in design. For the duties of Motor Statistician, a man should have a good education, should be adaptable to handling of details and should be familiar with gas engines.

The foreman of the storeroom is a Chief Machinist's Mate and is known as the chief storekeeper. He is responsible for having a stock of spare parts always on hand, and is also in charge of the toolroom. He has several stockroom helpers and toolroom assistants. A man who has had experience in a well organized stockroom and who can organize a stores system and handle men is desirable for this position.

The officer who has charge of engine work on the beach and in the hangars is known as the Outside Superintendent or the Squadron Machinist. He is responsible to the Squadron Commander.

The Squadron Machinist is in charge of a squadron which is composed of three divisions with six planes each, making a total of 18 planes. This officer should be experienced as an executive and should be especially familiar with trouble hunting in high-speed gasoline engines.

In charge of each division of six seaplanes is a Chief Machinist's Mate, known as the Division Machinist's Mate. He has six assistants to care for and to handle the seaplanes on the beach. He should be capable of handling men and should be well qualified in trouble hunting and making adjustments on aircraft engines.

There are several specialists in the outside working party. A Chief Machinist's Mate, as foreman of engine men, has several assistants who are specialists on the adjustment and care of aircraft engines. Another Chief Machinist's Mate is foreman of the accessory specialists, and a Chief Machinist's Mate is also in charge of the ignition specialists. There are two enlisted men to care for the pipe work on the seaplanes.

CHAPTER II

AIRCRAFT ENGINE PRINCIPLES

Introduction

7. Course, Duties of Officers, Equipment. The purpose of the Aviation Engineer Officers' Course is to provide officers and men to perform efficiently the duties of Engineer Officer and engineering assistants at Naval air stations. It is intended to select for this course men of mature judgment, who have had executive training and practical experience with gasoline engines.

Men with technical education will be preferred. A machine-shop training is also an asset. The course covers aircraft engines and their accessories in a broad sense, but is built principally around aircraft engines which are used by the United States Navy at the present time, special attention being given to the Liberty engine.

The various engineering duties on an air station and the qualifications necessary for each job were outlined in the preliminary lecture. The Engineer Officer must be familiar with the details of construction, operation, adjustment and care of aircraft engines and their accessories; also he must have broad enough training to direct all engineering work on an air station. All such work naturally falls under his supervision. At some air stations the Engineer Officer has supervision of the machine shop, engine-assembly shop, engine test stand, copper shop, ignition shop, all electrical work on the station, power, heat and light of the station, pump house, experimental work and, in some cases, the motor tuning on the beach. Comparing an air-station organization with a manufacturing organization, the Engineer Officer's position corresponds to that of factory manager. For direct assistants, the Engineer Officer has Warrant Machinists, their positions corresponding to those of departmental superintendents in a civilian organization. Under the Warrant Machinists are the chief machinist's mates and other chief petty officers, who act as foremen over the enlisted personnel.

The two main bases of United States Naval Aviation operations in Europe are at Queenstown, Ireland and Pauillac, France. In all, there were twenty-seven United States Naval air stations along European coasts at the time the armistice was signed.

A quotation from "The Army and Navy Journal," of December 7, 1918 states, "There are sixteen Navy aviation stations in France—nine

seaplane, three dirigible, three kite, one seaplane-training, covering the coast line from Dunkirk on the north, well down the west coast toward Spain. In addition there were bombing, training and supply stations. Several of the stations in France were equipped with land machines only. These collectively were known as the Northern Bombing Squadron. Several stations were also maintained in Ireland and England. An extensive station was located at Killingholme, which combined the work entailed in submarine hunting, convoying and long-distance bombing. In addition there were two stations in Canada and two in Italy on the Adriatic coast. At Pauillac there were 4,939 men, picked and trained, when the armistice was signed."

Nine of the sixteen stations were equipped each with 24 seaplanes of the H-16 type. Each H-16 has two Liberty engines of the Navy type. Six stations were equipped each with 16 seaplanes of HS-1 or HS-2 type. These seaplanes have one Navy type Liberty engine each. Five of these stations also have lighter-than-air craft. Each station is provided with a machine shop and with about 25 per cent. extra complement of engines. Spare parts are also kept on hand at each station. Early in the present war the United States Navy used Hall-Scott, Hispano-Suiza, Curtiss (various types), and Gnome engines. Some of these engines have been retired in favor of the Liberty 12-cylinder engine.

Other motors approved for use in U. S. Naval Aviation include the King-Bugatti, Kessler, Kirkham, Union Six, Duesenberg, the Hall-Scott L6, Beardmore, Rolls-Royce, Sunbeam Arab, RAF-3a, Siddeley Puma, Rolls-Falcon, Salmson, Mercedes, Beng, Argus and Renault.

Stations for patrol and for instruction of pilots are located at various points along the Atlantic and Pacific coasts, and on the Gulf of Mexico. The equipment at these stations ranges from 12 to 114 seaplanes. A number of these stations are also equipped with dirigibles and kite balloons.

It is interesting to note that patrol stations on the Atlantic coast alone employed over 500 seaplanes. In September, 1918, these patrols covered 404,775 miles. In this same period Navy fliers in training totaled 1,317,460 miles.

Suitability Elements

8. Weight per Horsepower. The power plant is the most essential element of the aircraft, for without it, aerial navigation would be quite impossible. An engine, to be suitable for the purpose, must possess certain characteristics never before required or produced by engine designers. Before aerial flights had actually been made no one could specify just what requirements an aircraft engine should meet, except that it should be as light as possible and not stop in the air.

At the period of experimental flight in 1901, the nearest approach to a

suitable engine was the automobile engine. The weight of this type of engine was approximately 15 lb. per hp., and the engine was uncertain in operation. An engine of this weight was too heavy, and a new design with reduced weight per horsepower, was necessary. The natural course was to take the automobile type of engine and lighten it by cutting down weights of the parts and by using lighter or stronger materials for some of the engine parts. The Wright brothers developed an engine of 12 hp. capable of making flight possible. The weight was reduced to 7 lb. per hp. Reduction of weight per horsepower has continued with the development of aircraft engines until engines weighing less than 2 lb. per hp. are now produced.

Low weight per horsepower being an essential requirement for aircraft engines, it is quite natural that *weight per horsepower* should be a basis used for comparing engines. The present Liberty engine (Army type) delivers approximately 400 hp. at 1,675 r.p.m. and weighs approximately 2.2 lb. per hp. This latter weight has varied considerably with the development of the engine. In the early stages of development the Liberty engine weighed less per horsepower than in its present stage. It was found, as a result of actual use of the engine under severe conditions, that several parts of the engine must be made heavier or of slightly different design, to increase the reliability of the engine. Naturally, the weight per horsepower was thus increased. To give an idea of the variation in weight per horsepower of various engines, the following table is shown:

TABLE I.—WEIGHT PER HORSEPOWER OF VARIOUS ENGINES

Engine	Rated hp.	R.p.m.	Wt. per hp.	Fuel consumption, lb. per hp.-hr.	Oil consumption, lb. per hp.-hr.
Liberty	400	1,675	2.2	0.54	0.025
Curtiss OXX6	100	1,400	4.2	0.537	0.021
Hispano-Suiza	150	1,450	2.96	0.54	0.033
Gnome 9-cylinder	100	1,200	2.8	0.80	0.25
Mercedes 8-cylinder	240	1,350	3.72	0.524	0.047
Benz 6-cylinder vertical	230	1,650	3.68		

The term, weight per horsepower, may be applied to an engine on four different bases: (*a*) on the basis of weight of engine stripped, just as it comes from the factory and without accessories; (*b*) weight with attached accessories, such as magnetos, pumps and carburetors; (*c*) weight with detached accessories, as radiators, tanks, batteries and instruments—really the entire power plant; and (*d*) weight including all accessories and supplies. This latter basis is the most important and is dependent on

the length of flight and the fuel and oil consumption of the engine. More will be said later concerning the importance of supply weights.

For a basis of comparing engines it is useful to know the engine weight per cubic foot of engine displacement. This is dependent on the design, arrangement of parts and of materials used. Factors concerned with power are thus eliminated. It is also important to know the horsepower per cubic foot of engine displacement. In comparing engines it may be found that high horsepower per cubic foot displacement may mean a heavy engine, while on the other hand an engine light in weight may prove to be low in horsepower. It is essential to compare engines on this basis. Note the variation in weight per cubic foot and horsepower per cubic foot displacement as listed in foregoing table.

Horsepower per cubic foot displacement is dependent on the mean effective pressure and the speed of the engine. Other things being equal, the horsepower of an engine varies directly with mean effective pressure, but unfortunately other factors do not stay the same. By *mean effective pressure,* with reference to aircraft engines, is meant brake *mean effective pressure* rather than *indicated mean effective pressure.* It will be explained in detail later that *mean effective pressure* is an average constant pressure which may be substituted in an engine cylinder to produce the same work as the actual varying pressures. The indicated *mean effective pressure* is found from indicator cards taken from the cylinder. On account of the high speed of aircraft engines, however, it is very difficult to obtain indicator cards. The brake *mean effective pressure* is therefor simpler to determine, and may be solved from the fundamental formula for horsepower:

$$\text{Hp.} = \frac{PLAN}{33{,}000}$$

where,
P = m.e.p. in lb. per sq. in.
L = stroke of engine in feet.
A = area of cylinder bore in sq. in.
N = No. of power strokes per min.

On a 4-cycle engine this is one-half the revolutions per minute: The number 33,000 remains constant (33,000 ft. lb.) per min. = 1 hp.

If P is the mean effective pressure in lb. per sq. in. obtained from an indicator card, the solution of the equation will be the indicated horsepower. On the other hand, suppose an engine is put on block test and the brake horsepower determined. Substituting this in the above equation, all factors are known except P. Solving for P,

$$P = \text{b.hp.} \times \frac{33{,}000}{LAN}$$

The brake mean effective pressure of aircraft engines usually averages between 110 and 120 lb. per sq. in. For automobile engines this value runs much lower, usually between 65 and 90 lb. per sq. in.

The horsepower of an engine varies with its speed. Therefor, without changing the weight of an engine the horsepower can be increased by increasing the speed. Consider next the effect of engine speed under engine weight. It is evident that in general the greater the speed, the lower will be the engine weight per horsepower. The effect of engine speed on engine reliability and engine life is also important. At the higher speeds the reliability and the life of an engine decrease. The fact that it is impossible to run aircraft propellers much above 1,600 r.p.m. must be considered also, as propeller efficiency decreases rapidly with increase of speed.

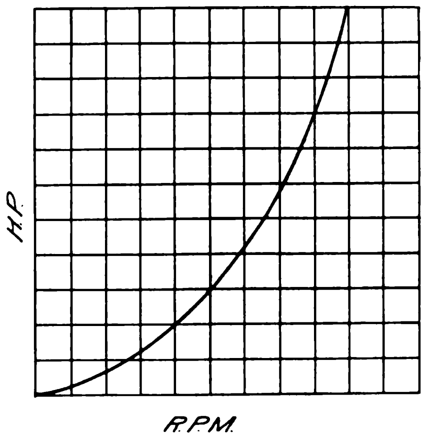

FIG. 1.—Characteristic curve of aircraft propellers.

For the Engineer Officer some propeller knowledge is necessary, although for operations he need not know propeller design, a subject which therefore will not be considered. A sketch of the *characteristic curve* of a propeller is shown. Such a curve gives the relation between propeller speed and the power necessary to drive the propeller. It will be seen that the horsepower required increases much more rapidly than the speed. Therefore, greater efficiency is obtained when running propellers at low speeds. Later, when the various forces produced in engine parts are considered, centrifugal force will be treated at this time. It is sufficient to state that the centrifugal force developed in the propeller is great and increases very rapidly with an increase of speed. In fact, centrifugal force varies as the square of the speed. To make possible the employment of high engine speeds a reduction gear is sometimes used. In such cases the propeller speed is sometimes as low as one-half the crankshaft speed, as on the Sunbeam engine which ran at 2 400 r.p.m. and employed a 50 per cent. reduction. The use of reduction gearing means additional weight to the engine and consequently an increase in the weight per horsepower. By the addition of the reduction mechanism the possibility of mechanical troubles is increased and the reliability of the engine reduced.

Engines can be made heavier or lighter than those produced at present, as engine weight is largely a question of materials. The selection of metals for the various engine parts therefore becomes an important as well

as complex problem. Various factors must be taken into careful consideration in making the selection of materials. Some metals will be selected on account of their high strength. Heat-treated alloy steels are extensively used in aircraft construction. Aluminum alloys are used on account of their lightness, and are proving especially satisfactory for crankcases and pistons. Aluminum cylinder blocks, with steel cylinder sleeves, are used in some aircraft engines. The thermal conductivity, or heat carrying capacity of the metal, must also be considered, for the problem of temperature control is one of the biggest problems of aircraft engine design and operation. The expansion of the metal due to heat must receive attention, too, as also the resistance to corrosion. Inasmuch as seaplanes are operated in the vicinity of salt water, the corrosion problem is an important one. Another requirement that must be met by metals is the maintenance of sufficiently high strength at high temperatures. Some metals decrease greatly in strength when heated. The lubricating qualities of the metal must also be considered. Some metals are very readily lubricated in contact with other metals and some are not. Cast iron in contact with cast iron is readily lubricated. Aluminum in contact with steel is also a good combination.

9. Reliability. Reliability is essential in aircraft engines. When this statement is made, the question naturally asked is what is meant by reliability, and how much reliability should be demanded. Reliability is a strictly comparative term. When it is said that a machine is reliable, it is reliable only in comparison with other machines of the same class, just as we say that a certain man is reliable in comparison with other men. In aircraft engine practice, there is no such thing as "absolute reliability," for an absolutely reliable engine cannnot be made. The degree of reliability is based upon two things:

(*a*) The length of time the engine will run before the power begins to fall off, and (*b*) the length of time the engine will run before coming to a dead stop.

While each of these is a measure of reliability, neither of them is a conclusive basis. Consider two engines compared on the latter basis. One may run for 50 hr. and be stopped by a broken camshaft, while the other may be stopped in 30 hr. due to the accidental opening of the ignition switch. Obviously, it would be wrong to credit the former as the better engine. The number of hours running, therefore, is neither a conclusive nor fair basis. Other factors have to be taken into account. The most satisfactory basis for comparing the reliability of engines is a detailed record of engine performance and of the running time before each replacement or adjustment must be made. A suggested method is to keep a record of the time of operation of the engine before each of the following operations has to be performed, as follows:

(a) Time when minor adjustments are necessary.
(b) Time when minor replacements are necessary.
(c) Time when major adjustments are necessary.
(d) Time when major replacements are necessary.
(e) Time when minor repairs are necessary.
(f) Time when major repairs are necessary.

Such a record of what each adjustment, replacement or repair consisted of, together with a tabulation indicating the minimum, maximum and the average time of each, will provide a basis for thoroughly understanding the engine and for predicting performance. This record also is very valuable in assigning engines and planes to their duties. For instance, suppose it were necessary to send an engine on a 30-hr. mission. If the record showed that the average life of a certain part of an engine was 50 hr., and the engine already had run 40 hr., it would be unsafe to choose that particular engine for the mission.

In connection with reliability, we often speak of the "life of the engine." This is an indefinite term, for when the various parts of the engine wear out or break, they are replaced and the useful life of the engine is prolonged indefinitely. In time, perhaps, all parts of the engine may be replaced and we really have a new engine, yet we still think of it as the original.

Having a record of actual operating conditions, the next thing to do is to use these facts to ascertain how to increase the time of operation. This requires an analysis of the causes of the failures. All power failures may be classified under one of the two headings:

(a) Mechanical (or metal) derangements.
(b) Process derangements.

Metal derangements are easily detected. They include:

1. Distortions, such as valve seats becoming warped; pins and shafts bent; and thermal expansions.
2. Burns, especially in combustion chamber parts, valves, etc.
3. Looseness and poor fit.
4. Adjustment and wearing, as valve gear and piston clearances.
5. Breakage of parts.

On early types of aircraft engines the tendency was to cut down the weight of all engine parts as much as possible. This increased the percentage of power failures due to mechanical derangements and seriously reduced the reliability of the engine. In the present stage of aircraft engine development, mechanical derangements are not so frequent.

The most important derangements are the process derangements. The three power processes to be considered are:

1. Mixture making and the introduction of the mixture into the cylinder. This includes a consideration of carburation and intake manifold.

2. Cylinder treatment of mixtures. This includes compression, ignition, combustion, expansion and exhaust.

3. Internal temperature control.

It is difficult to detect the approach of process derangements in an aviation engine just as it is difficult to detect the approach of disease in a person. The ability to diagnose the symptoms constitutes a good engine mechanic just as the ability to diagnose symptoms in persons makes a good physician. Metal derangements are easily detected amd may be compared to broken bones in a person.

One of the biggest problems of aircraft engine design and operation is the cooling of the engine. The rate of heat generation in aircraft engines is higher than in any other type of engine and it is a difficult problem to conduct the heat to a place of final disposition.

10. Adaptability. Special features are necessary in an engine to make it adaptable to aircraft service. Among these adaptability factors are:

Head Resistance. This is less important than formerly because the engine is now generally boxed in by a hood having a streamline effect. Air-cooled engine, however, are not usually covered with a hood.

Altitude.—This factor is due to the decrease in atmospheric pressure and temperature. It is for this reason that the Army type of Liberty engine is designed for a higher mean effective pressure than the Navy type. Certain types of army planes are now expected to be capable of ascending to an altitude of almost 30,000 ft. while necessity seldom requires a Navy plane to ascend more than 8,000 or 10,000 ft.

Atmospheric Conditions. Fog, rain, snow and winds must not affect the engine.

Dust. This factor is not so important in Naval aviation as in Army aviation. In Navy work, beach sand at times is blown on the engine and enters the cylinders through the carburetor, but the possibility of dust and dirt entering the cylinders is much less than in Army work where landings are often made on dusty fields. It is quite possible that a type of dust separator may be developed in the near future for use on aircraft engine carburetors. Such separators are now in use and proving satisfactory on farm tractors. When dry fields are plowed much dust is raised, and if it gets into the carburetor of the engine it does much harm, not only to the carburetor but also to the cylinders.

Shock and Shot Derangements. The engine may be subject to unusual stresses in bad landings of the plane. It is also liable to injury from bullets or other missiles in war.

Tilting. The engine should operate at all angles, and may even be required to operate upside down for short periods. The principal prob-

lems under these conditions are carburetion and lubrication. Government specifications for some aircraft engines call for a test of the engines tilted to an angle of 45 degrees.

Uniformity of Torque. Torque must be uniform, for sudden changes in torque may break the propeller or loosen it in the hub. When this occurs the movement of the propeller in its hub causes friction, resulting in the generation of heat and final charring or burning of the propeller. In some cases variation of torque may result in loosening the propeller hub on its shaft. There is a case on record in which the slight movement of the hub on the shaft resulted in welding the hub to the shaft. On engines of the automobile or stationary type, a flywheel is used to insure uniformity of torque. The use of a flywheel on aircraft engines is undesirable because of its weight.

Balance and Vibration.—It is important that the engine be well balanced. Synchronous Vibration must be considered. To illustrate what is meant by synchronous vibration, take the case of an automobile running along the road. As the speed is increased, a point is reached at which the entire automobile vibrates. As the speed is further increased this vibration disappears. The speed at which the vibration is greatest is called the "critical speed." Every piece of machinery has a critical speed which can only be found by experiment. It can be varied by redistributing the weight of parts of the mechanism. The critical speed of the Liberty engine with the heavy crankshaft is about 1,550 r.p.m. With the medium-weight crankshaft it was about 1,500 r.p.m. and with the light crankshaft 1,450 r.p.m. Running an aircraft engine at its critical speed, or running an engine which is poorly balanced, is hard on the pilot and on the entire airplane. One of the first parts of the machine to suffer is the engine support, which often breaks from the vibration.

Fire Risk. Precaution must be taken against leakage of oil over the engine which may be set afire from the exhaust or from back fire. Fire due to back fire in the carburetor must be guarded against also. On some carburetors a fire extinguisher is connected directly to the carburetor intake for emergency use. A frequent cause of fire has been the breaking of gasoline pipes when the airplane makes a very hard landing. When this occurs, the entire machine is enveloped in a gasoline vapor, and unless the engine has been shut off the exhaust ignites the vapor and the airplane is destroyed.

Air Gusts. Under certain conditions the atmosphere is not uniform in density. Air gusts and air pockets are common. When the propeller hits one of these air pockets, where the density is less than the surrounding atmosphere there is less resistance to the rotation of the propeller, and consequently a tendency toward sudden increase of engine speed. The action is very similar to the action of a propeller on a small launch. In

rough weather, sometimes the propeller is out of the water resulting in a sudden increase in engine speed.

Disposal of Exhaust. Various types of exhaust headers are used on aircraft engines. The general way is to lead the exhaust gases away from the pilot and observer and dispose of them with the least fire risk. It is desirable to muffle the exhaust, if possible, so that the pilot may observe any unusual noise in the engine, and to decrease the possibility of the enemy detecting the approach of the aircraft. Mufflers are not extensively used at the present time, and it is argued that the noise of the propeller and the vibration of the wires of the craft causes as much noise as the engine exhaust.

Accessibility of engine parts for adjustment, repair or replacement should receive consideration. On some types of aircraft engines it is necessary to remove many parts to get at the valves for grinding. On others the ignition system, especially the spark plugs, is very inaccessible. On some engines the replacement of cylinders is a difficult task due to inaccessibility.

The Aircraft Engine Problem

11. Analysis of Types. The answer to the problem of aircraft engine design and development is in the engines which have survived, and in the critical study of those engines which have been abandoned. Sometimes the abandonment of an engine has been due to lack of financial backing, or because the design seemed too radical. At other times abandonment has been due to small defects which could have been remedied. Most abandonments have been the result of some one or more fundamental defects. It is not within the province of this portion of the course to go into a detailed description of the various types of engines. Engine details of the various types and classes will be compared in detail later.

12. Total Power. The problem of aircraft engine building varies greatly with the size of the engine. For instance, the problem of designing and building a successful 500-hp. engine is not only different in degree but is different in kind from the design of a 100-hp. engine. It is an entirely different proposition from that encountered in building a bridge or a canal in which the problem of building a large or small one is essentially the same in kind but different in degree.

One of the biggest problems in aircraft engine design is to dissipate the heat so as to keep the engine sufficiently cool. The difficulty of dissipating the heat increases at a far greater rate than the horsepower increase. The total power, therefore, is an essential factor in engine construction. It may even be the limiting factor in the engine.

In 1914 the total power required of aircraft engines was only about 50 hp. Germany was the greatest developer at this time, for more

money was spent there in development work than in all other countries combined. In 1914 the German aviators called for engines of 80 to 120 hp. but were unable to procure the latter. In 1915 the Navy Department, probably prompted by the German progress called for engines ranging from 100 to 160 hp. Until this time no work along these lines had been done. Very few were forthcoming and at the beginning of the war nothing was available over 200 hp. Early in 1918 the demand came for engines of as high horsepower as possible, and official reports from abroad stated that engines of less than 400 hp. would be of no great value. To go from 200 to 400 hp. was an exceedingly difficult problem. To design and produce a successful engine to meet these unusual requirements meant the expenditure of much money, energy and time. American engineers decided to take all the best features embodied in the engines of both the Allies and the Germans and combine them in a composite model having few experimental features. It was desired to combine all the benefit of the experimental work done by the Allies and, at the same time, have the fewest possible number of types, a manufacturing policy followed by the Germans. The Liberty engine was the result.

13. Engine Speeds and Controlling Factors. The speeds which can be developed by aircraft engines will not be investigated. There are certain factors which control speed. In 1914 the Sunbeam engine developed a speed of 2,400 r.p.m. with a stroke of 6 in., giving a mean piston speed of 2,400 ft. per min. This is the greatest speed ever attained. Most aviation engines in 1914 had speeds of approximately 1,200 r.p.m., with strokes less than 6 in. A piston speed of approximately 1,000 ft. per min. resulted. The tendency at the present time is for the speed of the various makes of engines to fluctuate between 1,200 and 1,700 r.p.m. This variation in employed speeds is largely due to the conflict of speed control factors and to the difference in judgment as to the relative values of the following factors:

(*a*) *Mean Effective Pressure.* The mean effective pressure decreases as speed increases. As a result, the power does not increase directly with speed. This falling off being greater in some cases than in others. Engines suffering most from decreased mean effective pressure must run at low speeds. The two-cycle engine belongs to this class. In fact all engines using ports suffer more in this respect than those using poppet valves. In this type of engine, the fuel charge is admitted in puffs and the weight of the cylinder charge decreases as the speed increases. This cannot be avoided and is the main reason for engines of this type not meeting with favor in aircraft service. Among the four-cycle engines, which lose charge weight with increase of speed, is the Gnome. This is due to the fact that it employs ports for inlet of mixture to the cylinder.

(*b*) *Heat Development and Disposition.* As will be explained later, the rate of heat generation is higher in aircraft engines than in any other type

of internal-combustion engine. In the case of the Liberty engine, the amount of heat generated *per sq. in. of piston area*, this is the term employed to compare rates of heat generation, is more than three times that of some makes of automobile engines. It is a difficult problem to get rid of more than a certain amount of heat per minute. The limit probably has not been reached, but methods of getting rid of the heat are largely dependent on engine details and forms of construction and will be considered later.

(*c*) *Inertia and Centrifugal Forces.* These depend on the weight of the reciprocating and rotating parts respectively, and also vary as the square of the speed. Pressures and strains may become so excessive that the engine is rendered useless due to vibration, mechanical derangements, or the bearings may be loaded to a hopeless degree.

(*d*) *Cylinder and Piston Wear, and Lubrication.* Piston wear depends on the average pressure of the piston against the cylinder wall, and on speed. Side pressure is not very different in engines of similar type, hence wear may be said to be due to piston speed only. Therefore, the higher the speed, the greater the wearing will be, even on the assumption of equally good lubrication. A piston speed of 1,000 ft. per min. may be considered as a commercial standard inasmuch as stationary, marine and Diesel engines all seem to have about this range. Under this speed, the wear is inappreciable, but at speeds greater than this lubrication becomes of controlling importance. Under such conditions the lubrication must be excessive to prevent wear. Hence, piston speed may be said to be the controlling factor. Most modern submarine Diesel engines have a piston speed of not more than 950 ft. per min. This engine is said to be one of the most highly developed types of internal-combustion engine.

All of the above figures are based on the assumption that cast-iron pistons and cast-iron cylinders were used, as this material carries the best lubricating film. When other materials are used, such as steel or aluminum, the conditions for lubrication are not so favorable. Hence, more oil must be used, speed reduced, or our ideas on piston speed changed. The latter is the most rational. In aviation service, long life is not sought and the cylinder and piston problem is treated in the same manner as the crankshaft and its bearings, where no attempt is made to have a long life for either. Soft bearings are used so that practically all the wear comes where it is wanted, that is, on the part that is easily renewed. In aircraft-engine practice the same view is taken in regard to the cylinder and piston. The tendency is toward a steel cylinder and an aluminum piston, the latter being renewed when necessary. Therefore, the engine is no longer limited to low piston speeds.

(*e*) *Propeller Efficiency.* The efficiency of aircraft propellers decreases very rapidly with an increase of speed. Decrease in efficiency is not the

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only factor limiting speed, but propeller strength is also an important factor to be considered, especially for high powers. For example, a high-powered engine must have a long-bladed propeller, but the combination of long blades and high speed produces high centrifugal forces. Therefore, high-power propellers must be run at lower speeds. The propeller problem is serious when the propeller is on the engine shaft. This difficulty can be avoided to some extent by the use of gearing, although it does not meet with general approval and is used only as a last resort. The tendency today is to avoid gearing.

14. Unit Weight vs. Type of Engine and Duty. Fuel and supply weights together with engine weight per horsepower determine to a large

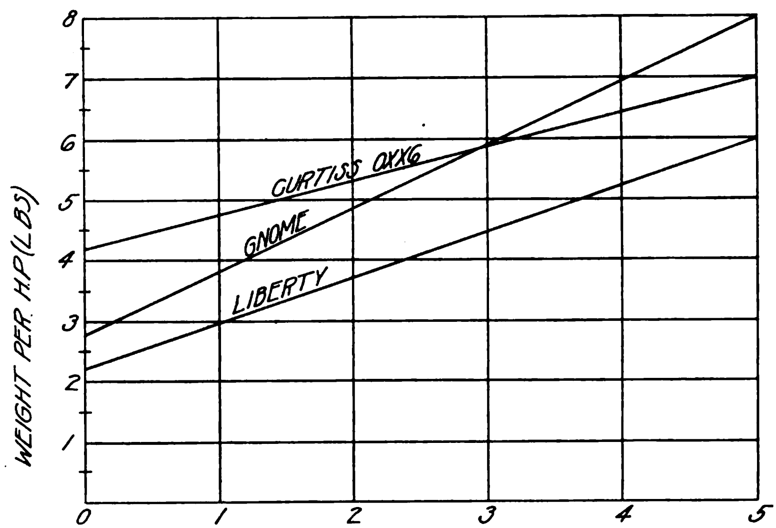

FIG. 2.—Bendeman chart.

extent the service for which an aircraft engine is most adapted, that of scouting, observation or bombing work. A satisfactory method of comparing engines on this basis is furnished by the following chart which was originated by Bendeman:

In this chart, weight per horsepower which includes engine plus supply weights, are plotted against duration of flight. The fuel weight to be carried per horsepower varies directly with the length of run and inversely as the thermal efficiency of the engine. It is also dependent on the grade of fuel, the carburetor adjustment and the running condition of the engine. The oil weight, while varying somewhat with the length of run, probably is not directly proportional to it and certainly is not dependent on the thermal efficiency of the engine, but rather depends on such factors as quality of the oil, mode of its application, style of engine, bearing temperature and surface pressure and speed. Water in

any properly proportioned jacket and radiator system should not be lost, and its weight may be regarded as a fixed quantity, independent of length of run and might be classed with metal weight. It needs only a superficial examination of these weights of accessories and supplies compared to engine weights to see that for short runs, engine and accessory weights are more important than supply weights, that for long runs the supply weights will become the controlling factors.

The longer the run, the more dependent plant weight becomes on thermal efficiency and on efficiency of lubrication. For example, the data of the second German competition test showed that the winning 100-hp. Benz water-cooled engine, weighing 4.2 lb. per hp. consumed 0.472 lb. of gasoline (thermal efficiency 29 per cent.) and 0.042 lb. of oil, or a total of 0.514 lb. per hp.-hr. The 70-hp. Gnome air-cooled engine, weighing 2.9 lb. per hp. consumed 0.805 lb. of gasoline and 0.253 lb. of oil, or a total of 1.058 lb. per hp.-hr. The conclusions drawn from the Bendeman chart, which shows that the weight of both engines equalize in 1½ hr., are that engines intended for short runs must be light and need not be especially economical if, by sacrificing economy, lightness is promoted. Conversely, engines intended for long runs must be economical at all costs, almost regardless of weight. It may be added that reliability is of importance about in proportion to the length of run. Short run engines must be light, even if less reliable. The reliability should be measured by period of uninterrupted operation. Considerable weight may be added to long-run engines to gain reliability.

Returning to the factors of plant weight, it is worth while to examine more closely the separate influences of the several component factors of accessory and supply weights. Radiator and tank weights vary greatly, and comparison by analytical methods do not show consistent results. The various types of radiators will be compared later and data on their weights given.

The purpose of the radiator is to keep the temperature of the jacket water below the boiling point, so that none is lost by evaporation. In so doing, its function is to transfer the heat of the water to the atmosphere. Knowledge of heat transfer is not sufficient to cover aircraft radiators because of disturbing conditions, such as air temperature versus power, or velocity versus power and temperature. Analysis of radiators shows that the most difficult problem in connnection with heat removal is the resistance to heat flow presented by the air film in contact with the radiator surface. Air is a very poor conductor of heat and it is essential that the air film, when heated, be swept away from the radiator surface and replaced by a new supply of cool air. The higher the velocity of air over the radiator surface, the more heat is removed from the water in the radiator, all because the film resistance is reduced.

Assuming the conductivity of air as 1, that of water may be considered

as 10, and metals as approximately 1,000. To illustrate, assume the heat to flow as a fluid through three pipes, the diameter of each of these pipes is represented by its rate of conductivity.

The heat travels from the engine cylinder walls through the water, the metal of the radiator and the air film successively. From the diagram it is plainly seen that, by an increase in the conductivity of the metal of the radiator, through the use of a different metal, the problem of heat flow is not helped. The resistance to heat flow is in the air film and not in the metal. The air film is the controlling factor and, as previously stated, can be reduced by velocity. A cellular radiator is very rapidly affected by change of velocity.

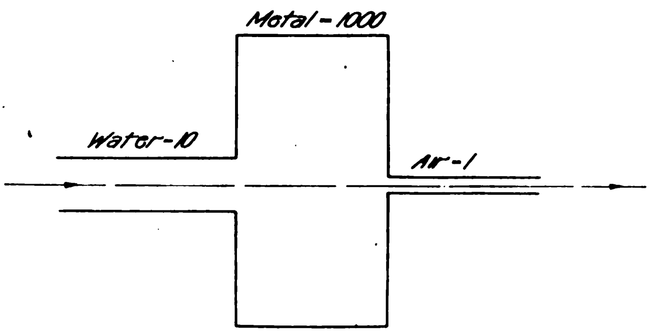

Fig. 3.—Relative conductivity.

15. Analysis of Parts Arrangement. No other branch of engine art has produced so many different arrangements of parts which have been termed engines. A multitude of freaks have been designed. The successes and the failures should be investigated so that it may be ascertained what points the successes have in common, what the failures have in common, and what is the probable cause of success or failure. In this way the successes may be perpetrated and the failures avoided, and only to the extent of one's knowledge of these can the relative worth of present-day engines be judged.

Aviation engines may be divided by cylinder and crank arrangement, into four classes, as follows:

1. Four or more vertical cylinders in line, each with its own crank, cylinder heads up; air or water cooled.

2. V-type, two rows of cylinders, of four or more each, inclined to each other with an included angle of 45, 60 or 90 degrees; one crank for each V-pair of cylinders; air or water cooled.

3. Radial cylinder type, rotating cylinders, crankshaft fixed, or rotating in same or opposite direction; air cooled only.

4. Special arrangements or combinations of the preceding.

The Germans adhere to Class 1, the Allies to Class 2. Class 3 is

good for short flights only. Class 4 includes most of the engines which have been abandoned. Students are advised to read up on the extinct types and as far as possible note the causes of failures.

Analysis of Operating Conditions

16. Functions of Parts and Design of Mechanism. Make.an analysis of the mechanism, forms of parts, designs and the various functions and operations necessary to perform the process requirements. In other words, note wherein an engine part is right, and a wrong one incorrect; also what conditions are necessary to secure proper combustion, what affects fuel consumption, engine power, engine and life. These must be known thoroughly to intelligently understand or operate an engine. No part can be designed, made or properly cared for unless one knows what its functions are to be, and how much to ask of it, without demanding too much. All parts must conform to fundamental process requirements. It is possible to have a variety of forms for some parts, or only one form, which can be told only by knowledge of these requirements. The first step will be to lay down as simply as possible certain laws on process requirements. Present forms of parts can be compared with forms which have previously been used, and discussed from the viewpoint of present requirements.

Fundamental Conditions for Operation

17. Mixture. The operation of any gasoline engine is fundamentally dependent upon certain power-making processes which when completely explained constitute specifications.

These processes are: (*a*) Mixture making and its introduction into the cylinder. (*b*) The treatment which the mixture receives in the cylinder. (*c*) Temperature control. It is necessary to study these processes in detail to qualify and to obtain the maximum power and economy of the engine under the various conditions peculiar to flight.

Mixture Making. As the source of power of the gasoline engine is the mixture of gasoline vapor and air, the first process is mixture making, preparatory to its introduction into the cylinder. The mixture-making process starts with the supply of gasoline and air at the carburetor, and ends at the inlet valve of each cylinder. The mixture-making process divides itself into (*a*) fuel supply, (*b*) air supply, (*c*) carburetor itself, which latter includes vaporization of the liquid fuel, proportioning the air and fuel, mixing them and maintaining a uniform mixture; and (*d*) mixture distribution to cylinders. What should constitute a correct mixture, and what harmful effects arise from an incorrect mixture must be known so that an improper one may be recognized.

In considering mixture making, the first concern is with quality of the

mixture, the second is with the quantity. The process may be said to be correct when both quality and quantity are correct, the mixture being considered in the cylinder, and not at some point between the carburetor and the cylinder. The best condition exists when the cylinder receives the maximum amount of mixture of the correct quality.

In order to obtain high efficiency and maximum horsepower when it is needed, it is obvious that the quality of the mixture supplied to the cylinders should be correct at all times and under all conditions.

Air-fuel Ratio. The first basis on which to judge quality is proportion. The proper proportion occurs when there is no unburned fuel and no unused air; an analysis of the exhaust gases should show no trace of unburned fuel or oxygen. If this is the case the proportion of air to fuel is as good as it is possible to obtain. For gasoline-air mixture the ratio is approximately 15 parts of air to one part of gasoline vapor by weight. If more than this amount of air is present, the mixture is said to be lean.

The first effect of a lean mixture is to reduce the speed of combustion, or the mixture takes longer to burn, much the same as in the case of dirty coal. The slowing down of the rate of combustion is considerable for even small amounts of excess air. The bad effect of slowing down the rate of combustion, arises from the fact that with the high speed as employed in aircraft engines, a very short interval of time exists for combustion. For example, assume that combustion must take place between 10 degrees of crank angle before dead center and 10 degrees after dead center; that is, in $\frac{1}{18}$ of a circle. If the speed be 1,800 r.p.m., or 30 revolutions per second, this allows approximately 0.002 of a second for combustion to take place. Unless the mixture is right, there is not sufficient time to develop the highest possible pressure. Hence, power and efficiency are both lost. In other words, excess air causes loss in horsepower and efficiency. Should the excess of air be considerable, there will be a further decrease in power and the phenomenon known as "backfiring" in the carburetor will result. Backfiring is not only annoying; it increases the fire hazard. Carried to the limit, excess air will produce a non-explosive mixture.

A slight excess of fuel increases the rate of combustion which condition contributes to increase of power at high speed. For this reason the average motorist will run his engine on a rich mixture. Such practice is undesirable because the increase in power is very slight, whereas the fuel is decomposed, carbon separating out which cannot burn for lack of air. A direct loss in thermal efficiency results from this unburned fuel. The carbon separates out as minute flakes of soot which will adhere to any cool surface, but any of it which comes in contact with a hot surface will not stick but pass on out of the exhaust and appears as smoke. Black smoke from the exhaust is therefore an indication of a rich mixture.

Any excess of fuel may just as well be thrown out of the tank direct instead of passing it through the engine. In fact this would be better, because carbon trouble would thus be avoided.

With much excess of fuel, carbon troubles and loss in thermal efficiency are intensified. Also, with a very rich mixture the mixture becomes slow-burning and causes a reduction of power. An analysis of the exhaust gases from a rich mixture will show the presence of carbon monoxide (CO), and unburned fuel, which indicates incomplete combustion. The soot which is deposited in the cylinder from a rich mixture accumulates and becomes highly heated, as will be later explained, and may result in the preignition of the cylinder charges of mixture. Soot deposited on spark plugs causes "missing" and ultimate stopping of the engine.

The problem of maintaining constant proportion is an especially troublesome one in aviation engines, inasmuch as all the difficulties common to stationary or automobile engines are present, but, in addition, there are those due to sudden changes of temperature and air pressure incident to rapid variation in altitude.

One of the factors that tend to destroy mixture quality is wetness. A mixture may be correct in proportions and yet be wet. A wet mixture is understood to mean a mixture in which the gasoline particles are in an unvaporized state or fog and is analogous to wet steam. With such a mixture, a slow manifold velocity will not keep the particles of gasoline in suspension; or, in other words, the particles of gasoline, being heavier than air, will have a tendency to fall back unless the speed with which the mixture travels through the manifold be sufficient to overcome gravity and carry the gasoline particles along with the air. There is a certain manifold velocity, therefore, that is necessary to maintain suspension. The manifold velocity may be sufficient at high speeds, but not at low speeds. Suspension of the mixture is therefore largely dependent on manifold design.

A manifold of small diameter may give a high velocity at low speeds, but with an increased surface friction; whereas, a manifold of larger diameter will offer less resistance to flow and yet not produce the desired velocity. What is desired then is a compromise between the two.

A manifold that is not smooth may allow the mixture to flow through the center at a sufficient speed, but will retard the flow of the mixture which comes in contact with the manifold walls. Gasoline particles will collect until there is a certain amount or puddle, which will then be carried into the cylinder in a lump or slug, causing a suddenly rich mixture, which in turn, will cause the engine to run in an uneven manner. Again, there are bends in the manifold that will cause trouble in a similar manner if too sharp. Gasoline particles will collect on the inside curve of the bend due to the lower velocity at that point, much the same as

floating objects in a stream will collect on the inside of the bend. The particles will accumulate until a puddle has been formed, which will be carried into the engine cylinder with the same effect as previously described for a very rich mixture. Usually this occurs when idling or when the velocity in the manifold is not sufficient to prevent the particles to collect on the way to the cylinder. Of course, if there is a jet action as the gases flow into the cylinder, then the mixing action is better. The ideal condition would result if the mixture were stirred by a mechanical device similar to an egg beater.

A mixture may have the proper proportions and still be lacking in uniformity or homogeneity. A homogeneous mixture is one where the constituents, which in this case are gasoline and air, are uniformly proportioned and thoroughly mixed throughout the mixture, every part of the mixture being exactly like every other part and with the same degree of vaporization of the fuel. Gases and air do not easily mix. Even worse is the condition of gasoline vapor and air. The mixture of gasoline vapor and air is a physical one and is difficult to make homogeneous, even though correctly proportioned and vaporized. The mixture may be vaporized and yet enter the cylinder in a stratified condition, or in layers of vapor and air. A mixture of this nature will be slow burning, as the flame in travelling through it will be retarded when striking the air layers. The layers of vapor, being in a concentrated state, will not completely burn and will leave a deposit of carbon.

A non-uniform or non-homogeneous mixture may be caused by incorrect manifold design such as sharp bends, excessive skin friction or slow manifold velocity. Any of these conditions may have a tendency to cause the mixture to enter the cylinders in a stratified form or in layers of air and gasoline vapor. Non-uniform or non-homogeneous mixtures are more frequently brought about by incomplete vaporization of the fuel. In the discussion of mixture making, it is assumed that the gasoline will vaporize and make a gaseous mixture with the air. All conclusions of what subsequently happens are based on this assumption. Inasmuch as this rarely happens the conclusions are not entirely correct. A very light gasoline, such as is used in gas-making machines, or what is known as "casinghead," will vaporize completely in summer, but ordinary gasoline never does completely. So there is always some liquid fuel in the inlet manifold. The lower the temperature of the air and the heavier the gasoline, the greater will be the quantity of unvaporized liquid. This liquid, being the last of the gasoline to vaporize, is made up of heavier portions and is practically kerosene. Sooner or later this mixture will strike a branch in the manifold, where it is supposed to divide to the various cylinders, each to receive its proper share. The proportions of air and gasoline for each cylinder are assumed to be the same. This, however, is not the case, for a wet mixture results in bad distribution,

one or more cylinders receiving more than their share of fuel. The wetter the mixture the more intensified this condition becomes, even if the proportions are correct at the carburetor.

Suppose some liquid actually gets into a cylinder, and that it comes into contact with a hot spot. It will vaporize, but the vapor will stay near the hot spot and will not mix with the air. Carbonization will occur even if excess air exists in other parts of the cylinder. On the other hand, should the liquid come into contact with a cold surface, such as the cylinder wall, no vaporization will occur, but the lubricating oil will be washed off. The unvaporized fuel will run down into the crankcase and destroy the lubricating qualities of the oil. Mineral oil is completely soluble in gasoline; castor oil is about 10 per cent. soluble. With 62° Baumé gasoline, a dry mixture is possible at 110° F. It is well to mention here also, that in the production of a true explosive mixture from this grade of gasoline there is a drop of approximately 35° F. during vaporization. Such lowering of temperature will naturally prevent vaporization to a great extent. As will be shown later, it is desirable to apply heat to the mixture to counteract this temperature drop and to thus assist in furnishing a proper mixture to the engine.

In connection with fuel quality, it is also necessary to consider neutral dilution, or the presence of some of the burned gases from the previous stroke. Neutral dilution causes a reduction in the rate of burning of the cylinder charge precisely as do excess air or fuel; and also tend to reduce the volumetric efficiency of the engine, a point which will later on be discussed in detail, first, because of the burned gases taking the place of so much fresh fuel charge that should have entered the cylinder; and, secondly, because the burned gases are at a relatively high temperature and tend to expand this volume of the fresh charge, thus reducing charge weight. As it is desired to get the maximum weight of mixture charge into the cylinder, neutral dilution is to be avoided as much as possible. Attempts have been made to lessen the quantity of burned gases that might be left in the cylinder by using a long exhaust pipe for each cylinder. In such a case the tendency is for the column of gas passing through the pipe to cause a vacuum behind it due to its momentum, and to drag some of the rest of the gas after it, which would otherwise remain in the cylinder. In this connection there is sometimes used an overlapping of the period during which the inlet and exhaust valves are open, that is, time the inlet valve to open before the exhaust closes so that the rush of escaping gases will help draw in the new charge. The Sturtevant uses this method. The intake opens 15 degrees before top center and the exhaust closes 10 degrees past top center. This allows an overlap of 25 degrees. The fact that the piston is practically at rest during this period prevents the drawing back of burnt gases from the exhaust. As previously stated the best conditions exist when the cylinder receives

the maximum quantity of mixture of the correct quality. The cylinders should receive the maximum possible quantity of mixture inasmuch as the mean effective pressure depends greatly upon the quantity of charge.

Quantity should be expressed by weight, because a given volume of gas will have different weights with different temperatures and pressures. As the weight is greatest with a low temperature and high pressure, it is essential to keep the charge as cool as possible and to have the pressure in the cylinders as high as possible when the inlet valve closes. Endeavor should be made to minimize those factors which tend to reduce the pressure of the cylinder charge. The pressure in the cylinder will be less than that of the atmosphere, or no flow into the cylinders would occur, and the amount of pressure below atmosphere depends upon all the inlet resistances combined, so there must be as large and smooth a passage into the cylinder as possible. For aircraft engines the atmospheric pressure is not constant, but decreases with increase of altitude. Consequently, the horsepower also decreases with increase of altitude.

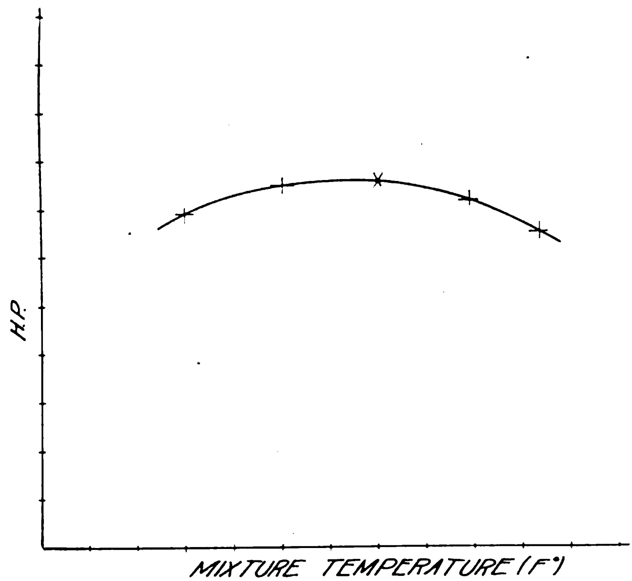

Fig. 4.—Mixture temperature (F).

As previously mentioned, the cylinder temperature should be as low as possible when the intake valve closes. For this reason the air should be as cool as possible on entering the carburetor and should have as little temperature rise as possible on the way from the carburetor to the cylinder. A conflict with former statements regarding fuel vaporization arises here, so there must be a compromise, it having been stated that to obtain maximum weight of mixture charge a *low* temperature is necessary and that to maintain good mixture quality a *high* temperature is

required. What should be done then is to make the mixture as cool as will be consistent with good quality and proper vaporization. Hence, there is a best temperature for any given gasoline. At this temperature maximum power occurs. A good method of determining the best temperature of mixture is to make a test of horsepower or revolutions per minute, which are obtainable for various temperatures of mixture for a fixed throttle position. When these results are plotted a curve as shown in Fig. 4 will be found for each grade of fuel. The temperature at which it is best to use this mixture is then the temperature corresponding to the highest point of the curve. With ordinary gasoline this temperature will be about 120° F.

18. Admission of Mixture into Cylinder and Treatment Therein. Assume that the mixture charge is in the cylinder. The first step thereafter is to compress it. Inasmuch as compression is a definite process its limits must be determined from the standpoint of efficiency and power. It is desirable to have all the compression that may be had, for the higher the compression the greater will be the thermal efficiency, the mean effective pressure, and the horsepower. As compression proceeds the temperature rises, and if carried far enough the charge will fire itself. This may be a cause of pre-ignition.

The Liberty engine for Navy use employs a compression pressure of about 110 lb. per sq. in. and develops 380 hp. The Army type Liberty engine employs a compression pressure of 120 to 130 lb. per sq. in., at which 425 hp. is developed. This difference is necessary on account of altitude requirements, the Army type being an engine for high altitude work. In this case the throttle must not be opened wide until an altitude of from 8,000 to 10,000 ft. is reached. In this way the charge weight is reduced at low altitudes, and the explosion pressure and mean effective pressure is reduced. Compression pressure depends on the clearance volume of the engine. Therefore, on the Liberty engine the only difference necessary to produce the higher compression used in the Army type is to employ a piston having a higher head than that used in the Navy type, thus changing the compression ratio.

The temperature of the cylinder charge at the end of the suction stroke is a factor in controlling volumetric efficiency, and hence mean effective pressure and horsepower. Also, the higher the temperature at the beginning of the compression stroke the higher it will be at the end of compression. If all the charge reaches the ignition temperature at the same instant the phenomenon known as detonation occurs. Detonation is the result of every particle of fuel uniting with the air at precisely the same instant. In ordinary combustion, on the other hand, the charge begins to burn at one spot, each particle of fuel burning in succession, even though the time for complete combustion be extremely short. The same distinction exists in two common explosives, gun powder and dyna-

mite, the former acting by combustion, the latter detonation. It rarely happens that all the mixture reaches ignition temperature at the same instant, however, because heat is received from the walls of the combustion chamber during compression as well as from the compression effect itself, and as the walls are not equal in temperature at all parts the gas nearest the hot spots will reach the ignition temperature first. The compression must be low enough so that the gas nearest the hottest spot will never reach ignition temperature during compression, for in that case self-ignition and partial detonation will occur.

Should any portion of the cylinder become coated with a layer of carbon, self-ignition will occur because carbon is a very poor conductor of heat, thus causing the surface to be red hot while the wall itself is cool. When self-ignition occurs prior to the desired time, as it usually does, it is termed pre-ignition. There is danger from carbon deposits in engines. The smallest spot is sufficient to produce the effect mentioned above, and trouble from it is particularly likely to occur in an engine which runs very warm or with a high compression since in this case the charge normally is nearly at ignition temperature. The aircraft engine comes in this class.

Assume that the mixture charge has been compressed to its fullest extent and still no ignition has occurred. The charge is now ready for ignition. Much literature and instructions have been contributed on the timing of the spark, but it is to be emphasized that the most important is *when combustion ends and not when it begins*. Suppose combustion to have been completed too early, that is, before the end of compression. High explosion pressure would thus be produced before the end of the stroke and the piston would have to compress the high-pressure gas, with resultant loss in power. The enine is also put to unusually high strains under such conditions. On the other hand, suppose combustion were not completed until half of the expansion stroke were over. The high-pressure gas is not available when wanted; it should be available as early as possible after top center has been reached. With the time of ending combustion fixed, the time when combustion should start is, of course, dependent upon how much time is necessary for combustion. As this time is variable, the greatest possible range should be provided in the mechanism for adjusting the time of beginning the ignition, so that the best point may be found by trial.

One reason why the battery-coil ignition system is preferable to magneto, especially in large aircraft engines is the wider range possible with it. The chief reason for the necessity of ignition time adjustment is the fact that at high speeds much less time is available for combustion than at low speeds. The action of the engine on poor mixtures may also be improved by change in ignition timing. Assuming that the mixture has the correct proportions of fuel and air, the speed of combustion will

be greatest when the least amount of burned gas is mixed with the new mixture. This greatest speed of combustion occurs at full throttle, while the largest amount of neutral dilution occurs when idling.

19. Cylinder Temperature Control. It has already been shown that excessive temperature is bad because of its lowering volumetric efficiency and limiting compression. These are known as gas effects, both of which affect power, and the latter of which also affects thermal efficiency. It is therefore important to devote much attention to keeping the engine cool. Consideration of the problem of engine temperature control must also be given from the standpoint of metal effects. These are:

(*a*) Expansion, which may be serious or not, depending on whether the member undergoing expansion is free or restrained. In the latter case distortion or possible breakage may occur. Expansion may be uniform or non-uniform. Warping or distortion result from non-uniform expansion.

(*b*) Binding on rubbing surface, as for example an overheated piston, or a valve stem without sufficient clearance.

(*c*) Burning or oxidization, as for example the exhaust valve or overheated piston.

(*d*) Weakening of the engine parts at high temperatures.

(*e*) Permanent growth; that is, some metals when expanded by heat do not return to their original size on cooling. This is especially true of cast iron of certain grades.

As previously stated, the rate of heat generation is greater in aircraft engines than in other types. Consider for a moment the combustion chamber of the Liberty engine without regard to other parts. Imagine the piston to form a fixed bottom. Under normal conditions the Liberty engine uses approximately ½ pound of fuel per horsepower hour. Assuming 20,000 B.t.u. per pound of fuel and a horsepower of 380. This would result in

$$\frac{20{,}000 \times 380 \times 0.5}{12 \text{ cyls.}}$$

or 316,000 B.t.u. per hour per cylinder. The cylinder diameter is 5 in. Therefore, the piston head area is 19.6 sq. in. The rate of heat generation then is

$$\frac{316{,}000}{19.6}$$

or 16,000 B.t.u. per sq. in. of piston area per hour, or about 268 B.t.u. per sq. in. of piston area *per minute.*

The temperature of engine parts is controlled by the following three factors, which will be considered in detail in a later lecture: (*a*) rate of heat generation; (*b*) heat paths; (*c*) means of heat dissipation. It is to be emphasized at this time, however, that the rate of heat dissipation of

any engine part must be equal to the rate of its heat reception. If the latter exceeds the former, the part will increase in temperature with possible harmful effects.

Horsepower—The Indicator and Diagram

20. Description of Instrument and Form of Diagram for Gas Engine. The indicator enables us to make a detailed analysis of the power processes with a view of establishing rules of procedure for analyzing them. The first power process, mixture making and introduction of the mixture into the cylinder, will be considered in detail under the subject "Carburetors and Carburetion." A complete picture of the second power process, cylinder treatment of the mixture, is shown by the indicator card.

One type of indicator frequently used for gas engine work is a Crosby external spring indicator, a cut and description of which are given below.

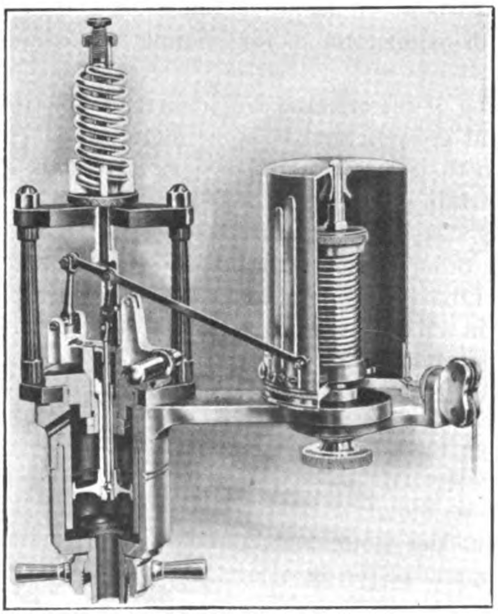

FIG. 5.—Crosby indicator.

The indicator is composed of a cylinder which is connected to the engine cylinder by means of a shut-off cock. Working in this cylinder is an accurately fitted piston free to move up and down. The piston is fastened by means of a linkage to a pencil mechanism so arranged that the point of the pencil travels in a straight vertical line directly proportional to the piston movement, the travel of the piston being restrained by the means of a spring connected to the pencil mechanism. These springs

are calibrated according to their strength, a spring marked 60 being called a 60-lb. spring. For example, a pressure of 60 lb. per sq. in. acting on the piston will cause the pencil to move just 1 in. Indicators are furnished with several different weights of springs to make them suitable for various pressures. The other part of the indicator is known as the drum and is used to carry the paper on which the diagram is drawn. The drum is connected by means of a string to some moving part of the engine, such as the crosshead or some other part which moves in the same relation as the piston. It is often necessary to use some sort of reducing mechanism to reduce the travel down to the limits of the drum travel which is about 3½ in.

To use the indicator it is connected to the engine cylinder; the drum is connected to the moving engine part, the cock opened and pressure allowed to act upon the piston. The pencil at the same time is held against the paper and a card is traced. The cock is then shut off, the drum disconnected and a line is drawn across the card by holding the pencil against the sheet, the drum being revolved by pulling the cord by hand. This is known as the atmospheric line, the indicator piston having atmospheric pressure against it, and is the datum or reference line for pressures.

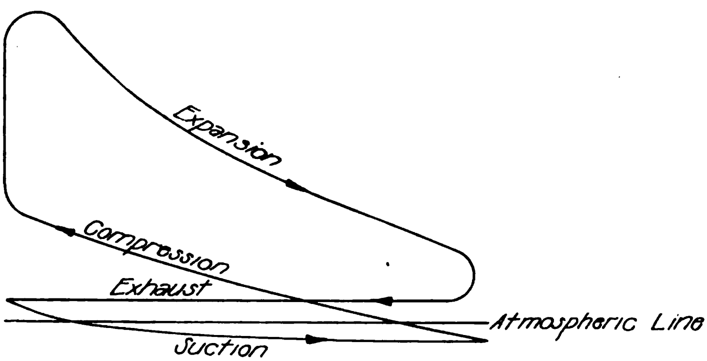

Fig. 6.—Indicator card.

The indicator works well on engines up to 500 r.p.m. but above that speed it is inaccurate due to inertia of the moving parts, both pencil mechanism and drum, and at 1000 r.p.m. will destroy itself. About 500 r.p.m. is the practical limit of speed at which indicators can be used. This of course eliminates their use for aircraft work. For higher speed work an instrument known as a manograph is used for this purpose. The construction of the manograph will not be dealt with because this can be found in many books in the testing of engines and in Chapter 5 of "High Speed Internal Combustion Engines," by Judge.

Form of Diagram for Gas Engines. While indicator cards of high-speed engines can be taken satisfactorily in a laboratory only, use will be

made of cards and the various lines of which they consist to explain engine operation and performance. This can be best explained by means of a card which can be assumed to have been taken from an engine and which represents four processes in the following order: suction, compression, expansion and exhaust.

The suction line *AB* is mostly below the atmospheric line due to resistance encountered during that stroke. The exhaust line is above the atmospheric line due to resistance encountered by the exhaust gases If resistances along the suction and exhaust lines and valve interferences could be eliminated these cards would appear as in Fig. 7, in which the suction and exhaust lines coincide with the atmospheric line. This is

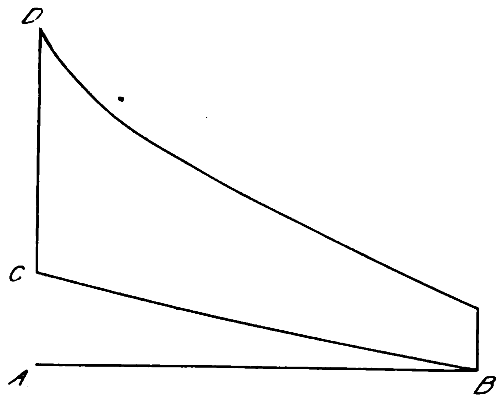

FIG. 7.—Ideal indicator card.

known as an ideal card. In taking a card from an engine the suction and exhaust lines come so close (much closer than shown in Fig. 6) to the atmospheric line that they can be considered coincident without any appreciable error. It is usual to consider the ideal diagram as being the same as the actual diagram taken from the engine.

The length of the card represents the length of the stroke of the engine and also the piston displacement or volume swept out by the piston, depending merely upon the scale. At the end of the stroke there is still some cylinder volume that the piston has not passed through, which volume is called the clearance volume and can be measured by putting the piston on upper dead center at the beginning of the power stroke and pouring a heavy oil from a measuring flask into the space through a spark-plug hole. The quantity of oil poured in, measures the clearance volume in cubic inches direct. Knowing the clearance of volume, it is possible to draw a vertical line to the left of the diagram and at a distance from it corresponding to this clearance volume.

This is shown by the distance *cl* in Fig. 8 below, *cl* being the

same per cent of the length of the card as the clearance is of the piston displacement.

The atmospheric pressure may be found by means of a barometer and there can then be drawn a line below the atmospheric line and parallel to it at a distance equal to barometric pressure, to the scale of the indicator spring; corresponding to zero pressure absolute. The pressure of the atmosphere at sea level is usually 14.7 lb. per sq. in. so the line can be drawn at that distance below the atmospheric line. The diagram now is complete and on it vertical distances represent pressures, and horizontal ones, volumes. The card now is known as a *pressure-volume diagram.*

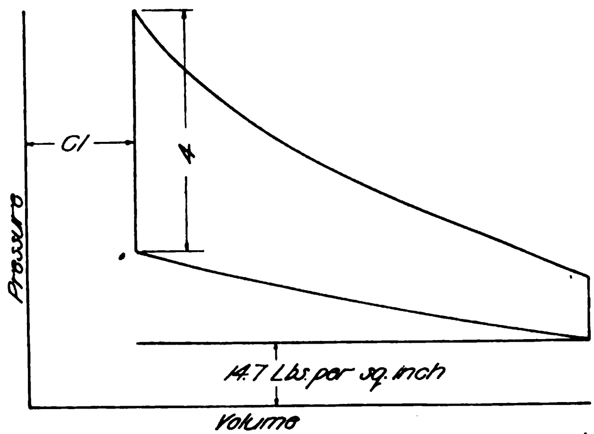

FIG. 8.—Pressure-volume diagram.

21. Work, Mean Effective Pressure, Indicated Horsepower. The area of the diagram, that is, the area enclosed within the lines of the case, represents the work done by the engine. It is the product of pressure and volume, or the product of pounds per square foot and cubic feet which gives foot-pounds, or work. The height of the explosion line *h* Fig. 8, is a measure of the heat supplied. As the area represents work and hence is a measure of power, the greater the area of the card, the greater is the power of the engine. The ratio of the area of the card to the height of the explosion line is a measure of the efficiency of the engine and hence of fuel consumption.

To determine the mean effective pressure (generally designated m.e.p.) from an indicator card, two methods are available, (1) the planimeter method and (2) the mean ordinate method. In the first method, the area of the card is accurately measured in square inches by means of a planimeter, and the length of the card is measured in inches. The area divided by the length gives the average height of the card in inches. Knowing the scale of the spring used in making the card, the product of the average height of the card, and the scale of the spring in pounds per

3

square inch gives the average pressure in pounds per square inch. This is the mean effective pressure, and is that pressure, which, if acting during one stroke would produce the same work as is actually developed in the four strokes of the cycle.

The second method used, if no planimeter is available, is to divide the card into divisions equally spaced as shown in Fig. 9.

The distance between *AB*, *CD*, *EF*, etc., are all equal. The number of divisions is immaterial, the greater the number the more accurate the result. The height of lines *AB*, *CD*, *EF*, ... *QR* is measured and recorded. Half the sum of the end ordinates (*AB* and *QR*) are added to

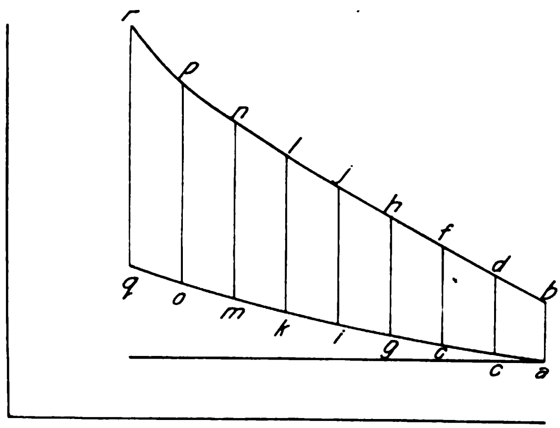

Fig. 9.—Mean ordinate method.

the height of the remaining ordinates. This sum divided by the number of spaces, one less than the number of ordinates, gives the average height of lines or the mean ordinate. This value in inches, multiplied by the scale of the spring, gives the mean effective pressure similar to the first method.

The product of m.e.p. and the area of the bore of the engine in square inches gives the force acting on the piston. Multiplying this product by length of stroke of the engine in feet, gives the work done in foot-pounds per cycle. The work done per cycle, times the number of cycles (power strokes) per minute gives the power developed by the engine measured in foot-pounds per minute; and this divided by 33,000 equals the indicated horsepower. The complete formula is:

$$\text{I.hp.} = \frac{PLAN}{33{,}000}$$

Where P = m.e.p. in lb. per sq. in.
L = length of stroke in feet.
A = area of bore in square inches.
N = No. of working strokes per minute.

For a 4-cycle engine, $N = \frac{\text{r.p.m.}}{2} \times$ number of cylinders.

In this formula the value of P is found from an indicator card and is called the indicated m.e.p. The power so found being determined by means of an indicator is known as the indicated horsepower, written i.hp.

Fuel Consumption and Efficiency

22. Thermal Efficiency. The ratio of work done by an engine to the heat of the fuel used, both being measured in the same units, either foot-pounds or British Thermal Units, usually the latter, is known as the thermal efficiency. In other words,

$$\text{Thermal Efficiency} = \frac{\text{Output}}{\text{Input}}$$

It is usual to reduce the output and input to the basis of 1 hp. for an hour. The output will then be 2,545 B.t.u. per hour. Hence,

$$\begin{aligned} 1 \text{ hp.} &= 33{,}000 \text{ ft.-lb. per min.} \\ &= 33{,}000 \times 60 = 1{,}980{,}000 \text{ ft.-lb. per hr.} \\ &= \frac{1{,}980{,}000}{778} = 2{,}545 \text{ B.t.u. per hr.} \end{aligned}$$

The input will be the number of pounds of gasoline used per hour by the engine divided by the total horsepower developed, which gives a figure of pounds of gasoline per hp. per hr. This result must be multiplied by the heat in one pound of gasoline which may be found from the formula:

Heating value (higher) of 1 lb. gasoline = 18,320 + 40 (Bé. − 10)

Where Bé. = Baumé gravity of gasoline.

Combining the output and input into one formula the following is obtained.

$$\text{Thermal Efficiency} = \frac{2{,}545}{\text{Pounds of gas per hp. per hr.} \times \text{heating value of 1 lb. of gasoline.}}$$

The effect of change of compression on thermal efficiency may now be considered. First, assume an engine fitted with elastic connecting rod which will allow the piston to move further into the clearance space, thus raising the compression pressure for the same length of stroke. The indicator diagram would look as follows:

The card *ABCD*, Fig. 10, represents the original card, while card *AEFD*, represents the card after increasing the compression pressure to an amount equal to *E*. The gain in area is *BEFG*, while the loss in area equals *GCD*. The gain exceeds the loss and the area of the card is increased. Consequently the power output of the engine is increased.

The height of the card, *BC* and *EF*, representing heat input, remains constant. Hence, with increase of compression, the power output is increased and the heat input kept constant. This gives a gain in thermal efficiency, showing that increasing the compression pressure gives an

increase of power and efficiency. Increase in compression can, however, be carried to a certain limit only, or preignition will occur. This limit will be discussed later.

The height of the explosion line is governed by the weight of the fuel charge, the greater the weight of charge the higher will be the line, and

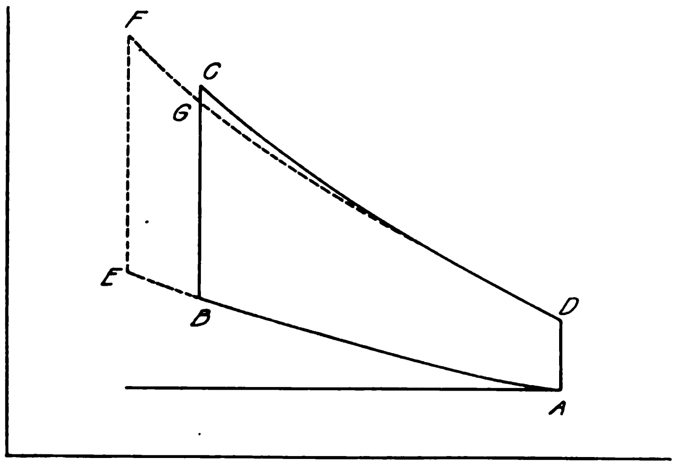

FIG. 10.—Effect of increasing compression pressure.

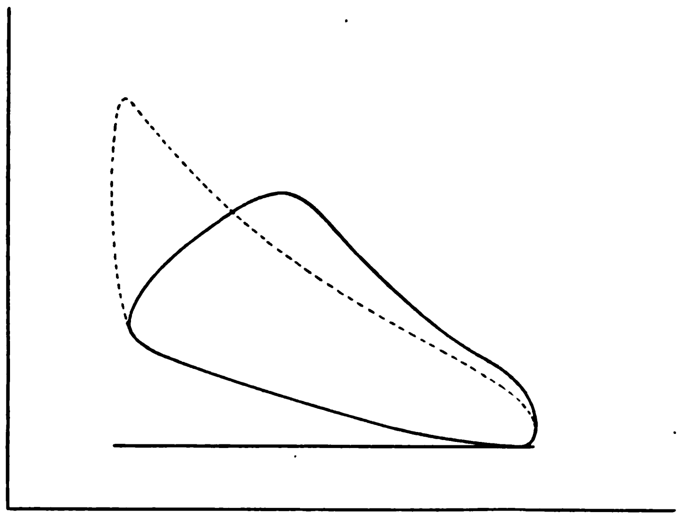

FIG. 11.—Slow burning mixture.

also the greater the area of the card; but the thermal efficiency will remain constant. Thermal efficiency, therefore, does not depend upon weight of charge.

If for any reason the mixture burns slowly from improper mixture, either lean or rich, the card will appear as in Fig. 11. The solid line

represents the actual card, while the dotted line shows the way the card should look with all adjustments and conditions correct. The area of the solid card is less for the same weight of fuel than is the area of the correct card; hence, the efficiency of the former is lower. Any card in which the combustion line shows a slow burning of the fuel means a lower efficiency.

If the mixture is very rich or very lean a card similar to that shown in Fig. 11 will result. In either case a decrease of power will result and the thermal efficiency will be consequently lowered. In the case of an excessively rich mixture much of the fuel will go through unburned, which further lowers the thermal efficiency. With a wet mixture, even though the proportions be correct, some goes through the engine in a liquid state. This of course does no work and is a waste, and a lowering of the thermal efficiency naturally results.

23. Mechanical Efficiency. An engine develops a certain horsepower in the cylinders, as shown by an indicator card. This is known as the indicated horsepower. Not all of this power is available for use, inasmuch as some of it is lost in engine friction. The horsepower which is available at the flywheel or propeller end of an engine is known as the delivered or brake horsepower (b.hp.), and may be measured by use of a Prony brake, a calibrated club, or by dynamometers of various kinds.

The difference between i.hp. and b.hp. is called friction horsepower (f.hp.). Friction horsepower is the power necessary to overcome the friction of the various parts of the engine, and also includes the power necessary to operate the valves, magneto and pumps, and generally that power required to draw in and exhaust the gases. Friction horsepower ranges from 15 to 25 per cent. of total power developed in aircraft engines. The ratio of b.hp. to i.hp. is known as mechanical efficiency or

$$\text{Mech. Effy.} = \frac{\text{b.hp.}}{\text{i.hp.}};$$

and this varies from 75 to 85 per cent. in aircraft engines.

Cylinder Charging vs. Power

24. Pressure Effect on Suction Stroke. Cylinder charging takes place entirely on the suction stroke, so, it is necessary to analyze what occurs on that stroke in order to correct any existing faults. To do this draw the suction line greatly magnified to show what occurs on that stroke, as indicated in Fig. 12.

The suction line starts at a distance above the atmospheric line, at the same pressure at which the exhaust line ends, being always slightly above atmospheric pressure due to resistances offered to the exit of the gases. This is, in amount, equal to the distance *A* in Fig. 12, and is

known as terminal exhaust pressure. At the start of the stroke the clearance volume is filled with exhaust gas from the previous stroke at a pressure equal to A, which is above atmospheric. This gas expands as the piston moves out following the law of adiabatic expansion (this law will be discussed later) until the point b is reached where the pressure is atmospheric.

There are certain resistances encountered before the charge can enter the cylinder, such as carburetor resistance, resistance of the inlet manifold, and resistance of the inlet valve, its seats and housing. It requires a certain lowering of pressure inside the cylinder to overcome these various resistances and this amount is shown on the diagram. Distance B, shows the lowering of pressure necessary to overcome the carburetor resistance; distance C to overcome inlet manifold resistance; and distance

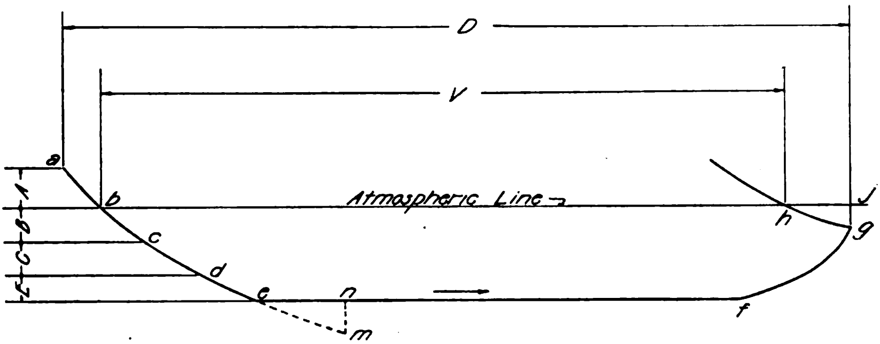

FIG. 12.—Suction line.

E to overcome resistance of inlet valve, seat and housing. When the pressure in the cylinder has reached an amount below atmosphere equal to the pressure at C, all the resistances have been overcome and the piston will draw in the charge during the remainder of the stroke.

The proper place to open the inlet valve is at the point E, just when the pressure inside the cylinder is reduced to the point where charging will start. It is of no advantage to open the valve too early as the charge would not flow in. If it were opened at A, some of the burnt gases would blow back into the inlet manifold. Opening the valve after E, or a late opening, would cause a lowering of pressure inside the cylinder beyond that which is necessary and cause a slight amount of negative work. (Shown by the area *emne*.) However, neither a small amount on one side or the other of the correct point E would cause any serious trouble or would it affect the power appreciably, so that it can be stated that the exact point of opening the inlet valve is not of great importance.

In fact the inlet valve opening may be considered the least important of the four valve-timing operations. On aircraft engines it usually opens from top center to 10° P.T.C. The charge enters the cylinder at a high

velocity, approximately two miles per minute. Toward the end of the stroke the piston slows down while the incoming gas still continues to flow in at high velocity due to its inertia. The gas strikes against the piston head, and a pressure is built up behind the piston, due to stopping the moving gas stream. This can be compared to the action of wind against the sail of a boat, where the velocity is reduced to zero when striking the sail, causing a building-up of pressure on one side of the sail. This effect is shown in Fig. 12 at *F*, when the pressure starts to increase. The part of the line *FG*, represents the building-up of pressure until the end of the stroke, where the compression starts. The pressure here will never quite equal atmospheric but will approach it closely.

The next point for consideration is the closing of the inlet valve. To get the maximum power of an engine it is necessary to get in a maximum weight of charge, and to do this the valve should be left open as long as any charge is flowing in. Due to the inertia of the gas, the charge continues to flow in during the start of the compression stroke, so the valve should be left open after dead center is reached, as long as there is any charge flowing.

The point to close the valve is that point of the stroke when the velocity of the incoming charge is just zero, and this of course will vary with the speed of the engine. It can be determined more readily for an aircraft engine than for an automobile engine, as the former is generally run at maximum speed at all times, while the latter is run at varying speeds. It is very important to determine the correct point for closing the inlet valve. If it be left open too long, part of the charge will be pushed back out of the cylinder into the intake manifold, and if the valve is closed too soon all of the charge cannot get into the cylinder and the power will be lowered. In actual practice the point at which the valve should close is determined experimentally by varying valve-closing and determining the one for which the engine develops the greatest speed or power. The closing of the inlet valve is the most important of the valve-timing operations.

Referring to Fig. 12, note where the suction line cuts the atmospheric line at *b*, and where the compression line cuts the atmospheric line at *h*.

The increase in volume is represented by *kb*, which would be occupied by the gases remaining in the clearance space from the previous charge if the pressure were reduced to atmospheric. The loss of new charge, due to low suction pressure, is represented by *hj*, inasmuch as the volume in the cylinder at the end of suction would occupy less volume by the amount *hj*, if the pressure became atmospheric. The distance *bh* or *V* represents the volume of charge drawn in at atmospheric pressure. As the volume of a gas varies with the pressure, it is necessary to have different volumes at the same pressure when comparing them, and the pressure usually chosen is that of the atmosphere.

The piston should have drawn in D cubic feet of charge as that is the volume swept out and equals the piston displacement, but the volume actually drawn in is V. This quantity divided by the piston displacement D, is called the apparent volumetric efficiency, or,

$$\text{Vol. effy.} = \frac{V}{D}$$

The greater the volumetric efficiency the greater will be the m.e.p. and power of the engine, so high volumetric efficiency is most desirable.

25. Temperature Effects on Suction Stroke. The volume of a given weight of gas varies with temperature as well as with pressure. Increase in temperature causes an increase in volume, the pressure being constant, and inversely the weight of a given volume decreasing with rise of temperature. The temperature of the incoming charge is increased during the suction stroke due to contact with hot metal and other causes, and is considerably higher at the end of the stroke than is the atmospheric air which is taken in.

The volume V, which is at atmospheric pressure, is heated and consequently does not weigh as much as would the same volume of gas measured at atmospheric temperature. As it is weight of charge, and not volume, that determines power, it is not fair to compare the heated volume of gas inside the cylinder with the same volume of cooler gas. Hence, the efficiency, neglecting temperature effects and as found from a card, is called *apparent* volumetric efficiency as it is not the true measure of efficiency. A comparison will possibly make this clear. Suppose rubber tubing, such as is usually sold by the yard, were to be bought and a yard of it is desired. The salesman in measuring the tubing stretches it and cuts off a yard. Apparently there is a yard, but as soon as he releases his hold on the rubber it returns to its original shape and actually there is less than a yard. So with the gas. A certain volume measured at high temperature is actually less when measured at atmospheric temperature. It is therefore desirable in the interest of high-charge weights to keep the temperature along the suction stroke as low as possible.

The reason why there is a change in temperature on suction can best be seen by tracing the incoming charge from its entrance into the carburetor to the end of the suction stroke and see when it receives heat. Air first enters the carburetor at atmospheric temperature and is cooled by the vaporization of the gasoline from 20 to 35 degrees below its initial temperature. It then goes up the riser and inlet manifold, getting a slight amount of heat from them. On some engines the riser and manifolds are jacketed either with hot water, as on the Liberty, or with hot oil as on the Hall-Scott. Further heat is given from the inlet-valve seat and housing, and from contact with the inlet valve which depends to a

great extent on this sweeping by the incoming charge to keep it cool. The gas then sweeps around in the combustion chamber getting heat from its walls, the piston head and the exhaust valve. It also mixes with the burned gases remaining from the previous stroke, that could not be completely expelled, and which are the greatest source of heat.

A certain amount of heat on the suction stroke is desirable, for sufficient heat should be applied to the gas to completely dry it. That is the function of the jacket around the intake riser and intake manifold. Any additional heat beyond that to dry the gas will cause a lowering of power by reduction of charge weight; hence, the balance of the heat added along the stroke is undesirable but unavoidable. All heating effects which are undesirable should be kept as low as possible.

It is possible on large stationary engines to water-cool both valves. This will reduce slightly the temperature of the charge. The temperature of the burned gases should be kept as low as possible and anything which tends to heat them should be avoided, as for example, running with a retarded spark, or rich mixture.

As stated before, the volumetric efficiency obtained from an indicator card is the *apparent volumetric efficiency.*

To get the real volumetric efficiency it is necessary to use experimental means. The engine is run and the volume of air going in through the air intake of the carburetor is metered and from the number of revolutions the engine makes in a definite time, the total piston displacement can be calculated. The ratio of air drawn in, from meter reading, reduced to standard conditions, to the total piston displacement is the *real volumetric efficiency.* This method ignores the volume of the gasoline as it introduces no appreciable error.

Compression vs. Power and Efficiency

26. Compression Pressure. After the suction stroke is complete the compression stroke starts. The compression line follows a definite law known as adiabatic compression. An adiabatic compression is one in which a gas is compressed at constant heat, or when the pressure and temperature of the gas is raised without the addition or subtraction of any heat. The general law for such a compression is PV^s = constant, where P represents the pressure, V the volume and s the exponent depending on the gas compressed. For an absolutely tight cylinder and piston, and using air as the substance to be compressed, the value of s is 1.406 and is known as the maximum value. If the cylinder has slight leaks, as is true commercially, and a gasoline-air combination is being compressed, the value of s is 1.33, which is called the minimum value. As it is very difficult to ascertain exactly the quality of mixture being compressed, and just how much leakage there is, it is generally assumed that the real compression line lies somewhere between these limits.

As was shown before, by means of the assumption of an elastic connecting rod (Fig. 10), that increasing the compression pressure increases the area of the card and, hence the power. As the amount of fuel used is not changed, the thermal efficiency is therefore increased. Compression pressure can be carried to a certain limit only. Too high compression pressure will cause preignition, the charge igniting from the heat developed by its own compression.

The compression pressure of an engine is either too high, correct or too low. If it is too high, persistent preignition will occur. The only remedy is to lower the compression pressure by using a shorter piston on a shorter connecting rod. If there is no preignition the compression is either correct or too low. The usual shop method is to increase the compression by changing the piston or rod and trying again. Such a method is troublesome. If the compression were correct at the start this increase will cause preignition, and the engine will have to be rebuilt and restored to its original condition.

A better way is to heat the entering mixture by using a blow torch on the inlet manifold. A thermometer should be inserted in the man'fold and heat added until the engine knocks. The knocking indicates preignition. It can then be calculated how much additional compression the engine could have carried to give the same effect as the added heat.

Compression pressure should be the same in every cylinder. This item should be frequently checked. Compression pressure may be measured by putting an indicator on each cylinder and cutting out the spark on the cylinder being tested. The height of the compression line measured to the scale of the spring gives the compression pressure. Another method is to use a gage with a check valve and attach it to the cylinder, running without a spark. The gage will indicate the compression pressure. Both of these methods are rather difficult to carry out on high-speed engines.

A persistent search should be made for leaks. This should be a part of the regular inspection schedule. One method of detecting leaks is by means of an indicator card as follows: Attach the indicator and run the engine with spark off on that cylinder. If there are no leaks the pencil will trace up and down on the full line "*a*." If there are leaks the pencil on the return stroke will trace along the line "*b*" showing that some of the charge has leaked out.

Another method of testing for leaks is to fill the cylinder with gasoline and note where it leaks out. This is not a very good method as the gasoline may evaporate and not show the leak, or it may cut the lubricating oil causing a leak past the piston rings which ordinarily would not exist. Still another method is to fill the cylinder with illuminating gas or acetylene under slight pressure and trying to find leaks with a flame. Still another method is to fill the cylinder with compressed air. Have a

gage connected to the cylinder and note by means of a stop watch the time required for the pressure in the cylinder to fall, say from 60 to 40 lb. Knowing this for a reasonably tight cylinder it is possible to ascertain if leaks exist. Compression leaks occur, (1) past piston and rings; (2) at inlet or exhaust valve seat; (3) at spark plug hole or body of plug, and (4) at hole in the metal of the cylinder or piston. There are also leaks past inlet and exhaust valve stems and leaks past the inlet manifold gaskets. These latter leaks do not affect the compression but cause air to leak in on the intake stroke producing a lean mixture. This is particularly serious when the engine is throttled down and the pressure on suction is thereby greatly reduced.

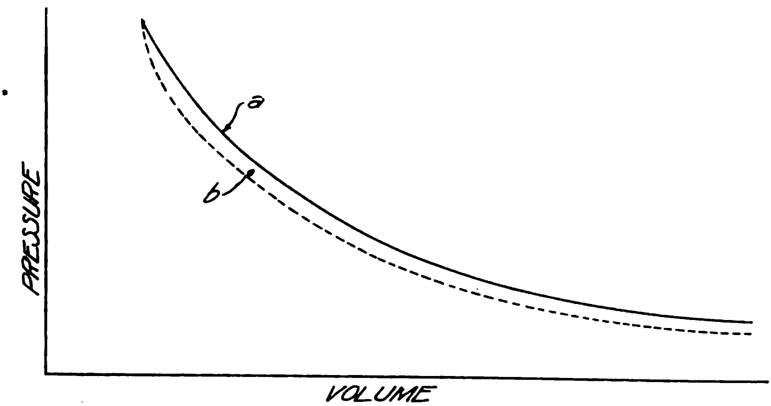

FIG. 13.—Indicator-card method of determining leaks.

27. Compression Temperature. Increasing the pressure of the mixture during the compression stroke increases its temperature. There is a certain temperature to which a gasoline-air mixture can be raised, and beyond which it cannot go without igniting. This temperature for a perfect mixture of gasoline and air is 986° F. At that temperature the mixture will ignite due to the heat of its own compression. If neutral gases (burned gases from previous stroke) are introduced into this mixture, the ignition temperature is raised to approximately 1000° F. This temperature is the ultimate limit. In practice the temperature of the gas at the end of compression should not be that high; it should be carried to a safe figure only. A safe temperature is 750° F., which allows a factor of safety against local hot spots. There are two factors tending to a high temperature at the end of compression, namely, high compression and high temperature at the end of suction. In order to carry as high a pressure as possible and corresponding high efficiency, it is necessary to keep the suction temperature as low as possible. The following table shows the relation between suction temperature and compression

pressure that may be attained without the compression temperature exceeding 750° F.

TABLE II.—SUCTION TEMPERATURE, COMPRESSION PRESSURE

Temp. at end of suction, ° F.	Compression pressure, lb. per sq. in. above atmospheric	
	Min. ($s = 1.33$)	Max. ($s = 1.406$)
200	193	293
300	110	155
400	67	92
500	41	52
600	23	31

The maximum and minimum values of pressure are given, the actual pressure being somewhere between these limits. It can be seen that the higher the suction temperature the lower the compression pressure that can be carried. The Liberty engine having a compression pressure of 110 lb. per sq. in. has a suction temperature between 300 and 400° F.

Combustion and Expansion vs. Power and Efficiency

28. Ignition. After compression is complete combustion takes place. To start the combustion some source of heat is necessary to raise a portion of the gas to ignition temperature. The most convenient means to ignite the mixture is the electric spark. This is positive in its action and can be perfectly produced and controlled. The spark for aircraft engines is produced either by a high-tension magneto or by a battery-coil breaker system such as the Delco.

29. Combustion. The spark occurs, heating the gas between the points of the spark plug to ignition temperature. The combustion of this small amount raises the temperature of the immediately surrounding gas to ignition point. The flame travels through the mixture igniting one part after the other. This phenomenon is called flame propagation. The speed with which the flame travels through the mixture depends on several factors of which the quality of the mixture is the most important. If the mixture is very rich, there is insufficient air to burn the fuel, and the burning is slow; while if the mixture is lean, there is too much air, and the burning is also slow. Another factor is proper mixing of the air and gas for the proportion may be correct and yet, if the mixing is not complete the burning will be slowed down. The effect of neutral dilution lowers the rate of flame travel.

In the development of the aircraft engine it was found that the time available for combustion was very short and that it was impossible with one spark to ignite all the mixture quickly enough to insure complete

combustion in the time allowed. This led to a more careful study of spark-plug position in the cylinder and the number of plugs to use. The following diagram in Fig. 14, represents different spark-plug positions and shows the effect of position on flame travel:

Flame propagation takes place in all directions at the same time. Therefore, the ideal shape for a combustion chamber is spherical, with the spark plug at the center of the chamber. This is impracticable so the next best place is the center of the cylinder head, as shown in *A*, Fig. 14, the flame travels outward and downward from the center.

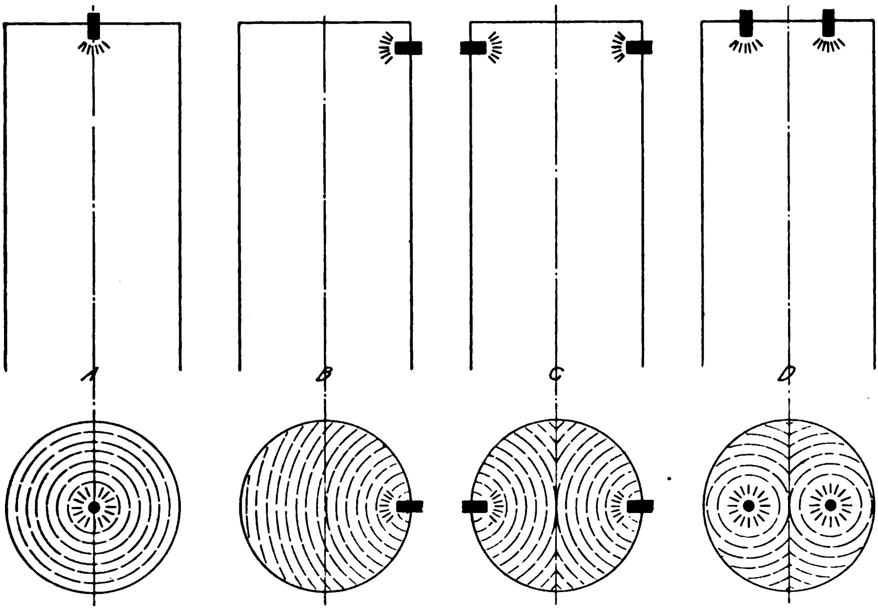

Fig. 14.—Effect of spark plug position.

Another method is to place the plug in the side of the cylinder as shown in *B*, Fig. 14. It can be seen that it will take more time for the flame to travel through the mixture in the case of *B* than in the case of *A*. The next arrangement, *C*, shows two plugs placed on opposite sides of the cylinder. This arrangement is more effective than *B*, as the flame travels just half the distance. The best arrangement is shown in *D*, where two plugs are placed in the top of the cylinder, and the flame is given a chance to spread through the mixture in the least possible time. This method is used on the Liberty engine regardless of the fact that such a position places the plugs where they are quite inaccessible and difficult to replace. When using two plugs it is absolutely essential that both fire at *exactly the same time*. If one plug lags behind the other the function of both plugs is impaired. The flame may have spread from the first plug

beyond the second plug before the latter produces its spark. Thus the purpose of the second plug will be defeated.

Fig. 15 shows a section of the indicator card for ideal conditions of ignition and combustion. The spark occurs at the end of the compression stroke and the burning is instantaneous requiring no time interval. The corners of the card are sharp with resultant vertical explosion line. Actually this condition does not exist for it requires a definite time for the charge to burn. It is desirable to complete the combustion as close to top center as it can be done, leaving all the time possible for expansion. This combustion should be complete about 10 to 20 degrees of crank angle

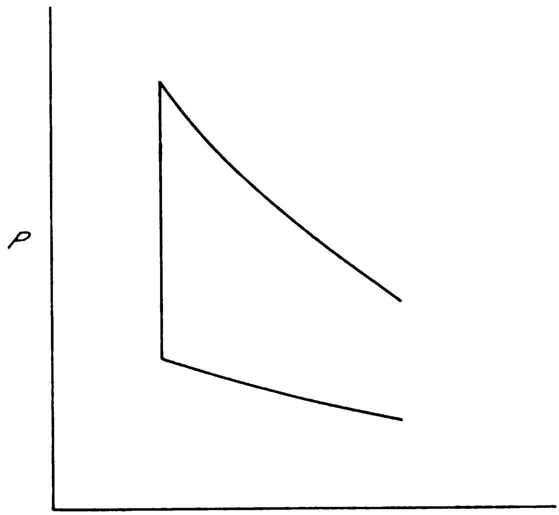

FIG. 15.—Ideal ignition and combustion.

past top center. As it requires a definite time to burn the charge, it is necessary to start the burning before top center to complete it by that time. An actual card is shown in Fig. 16, the corners being rounded, showing the early start of the combustion and the ending of combustion after top center.

The higher the speed of the engine the earlier is it necessary to start the combustion. This is accomplished by doing what is known as *advancing the spark*, the effect of which is shown in Fig. 16, by the dotted lines. Since the time necessary to burn the mixture is fixed, the higher the speed of the engine the greater becomes the necessity for advance of spark, in order to have the combustion finished at the correct time.

It is possible, however, to get the timing too early or too late. Fig. 17 shows too much advance giving the solid-line card, the sectional area representing negative work and a loss in power. The dotted line shows a correctly timed card. Too early ignition causes a knock in the engine,

has a serious effect on the bearings and also causes loss of power. Fig. 18 shows a case of too late ignition, the ignition not occurring until after top center. By this time the piston has begun to move so that the volume is continually increasing and the pressure cannot build up to its full value.

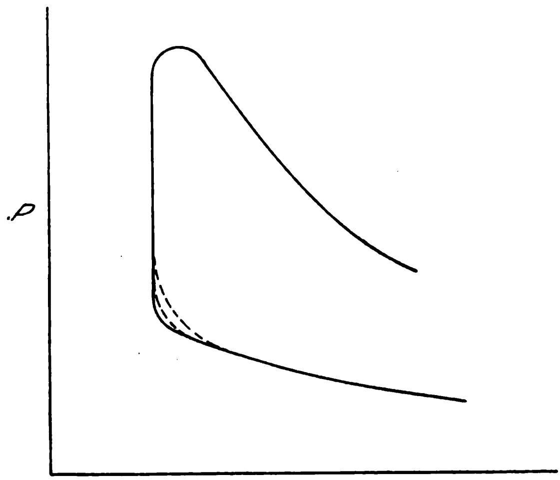

FIG. 16.—Actual ignition and combustion.

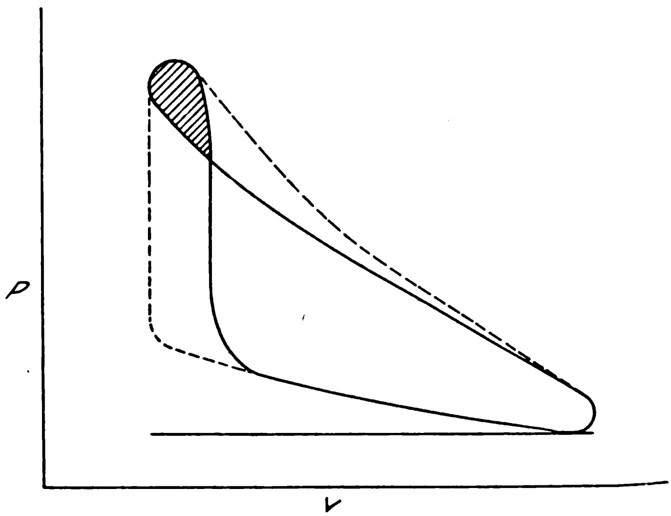

FIG. 17.—Too early spark, preignition.

A correctly timed card is again indicated by the dotted line. The pressure at the end of expansion for the late timed spark is higher than for the normal card and the temperature at the end of the stroke will also be higher than normal, which unduly heats the engine and causes increased

heat losses and lower thermal efficiency. Late spark also causes a loss of power as can be seen by the smaller area of the card.

The quality of the mixture affects the combustion line. If the mixture is rich or lean the burning will be slower, as is shown in Fig. 19. For a fairly poor mixture, either rich or lean, the effect will be the same.

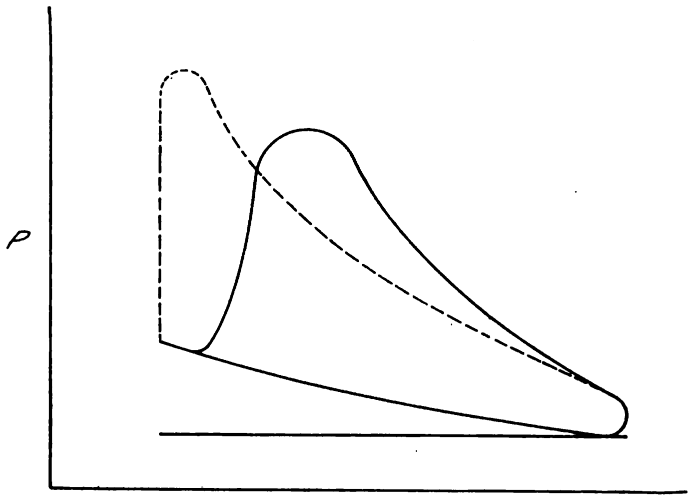

FIG. 18.—Retarded spark.

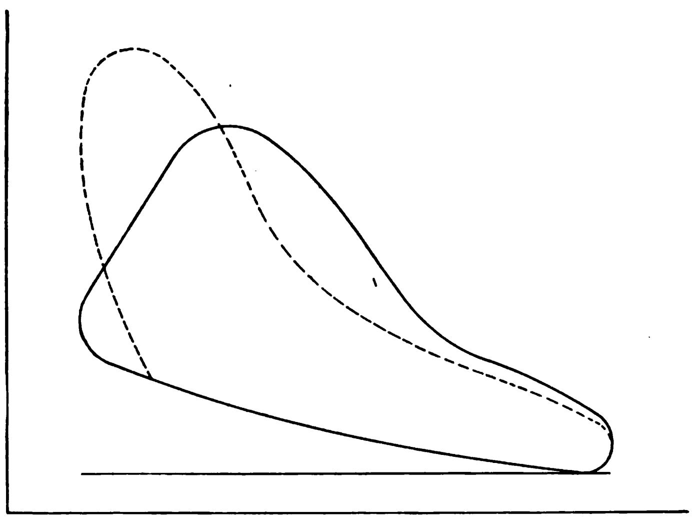

FIG. 19.—Rich mixture, slow burning.

To overcome to some extent the effect of this slow burning, the spark may be advanced. An advanced spark will start the combustion earlier and the burning will be completed sooner. This is shown in Fig. 19,

by the dotted line. Advance of spark will assist to a slight extent an improper mixture, but is not to be considered as a remedy.

Cylinder Exhaust Analysis

30. Exhaust Valve Lead and Terminal-exhaust Resistance. The next cylinder process after combustion is expansion. If combustion is correct and properly timed, there is little to be said about expansion as it

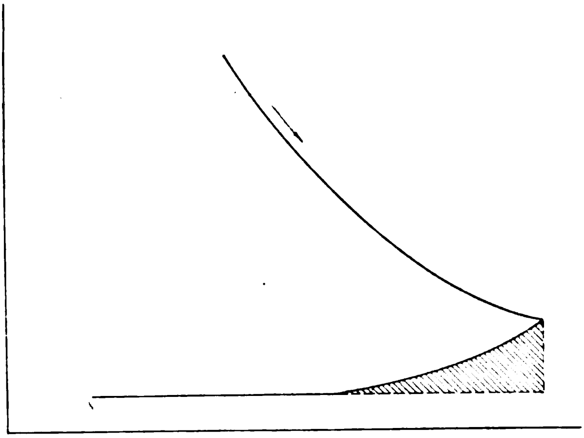

Fig. 20.—Early opening of exhaust valve.

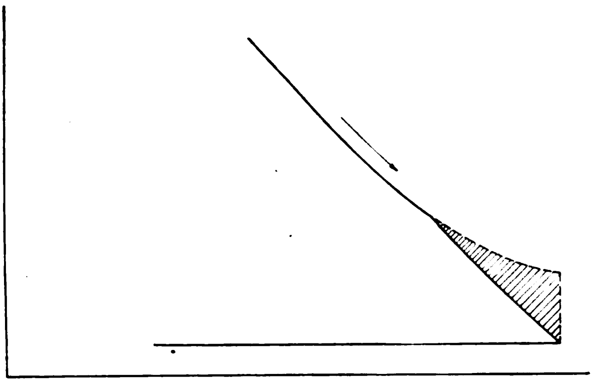

Fig. 21.—Late opening of exhaust valve.

will take care of itself. The point of interest, however, is the end of the stroke when the exhaust valve is opened. The point of opening the exhaust valve has an important effect on the power of the engine.

Fig. 20 shows a very early opening of the exhaust valve at 90° P.T.C. The sectional area shows work lost resulting from too early opening of the exhaust valve. Such timing is not used on any aircraft engine except the Gnome. It is necessary in that engine to open the

valve very early to reduce the pressure in the cylinder to atmospheric pressure in order to draw in a charge.

Fig. 21 shows a late opening of the exhaust valve, at bottom center. This causes a loss of work as shown by the sectional area. The correct point at which to open the valve is midway between the two, or approximately 45° B.B.C. on the power stroke. This gives a card, as shown in Fig. 22, in which the loss is reduced to a minimum and is equally

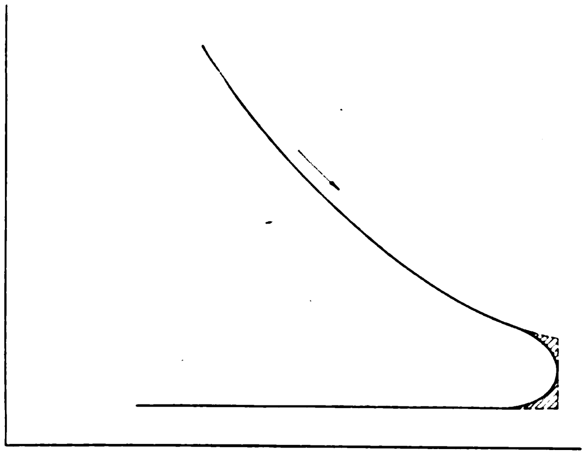

FIG. 22.—Correct exhaust valve opening.

distributed between the expansion and exhaust strokes. The opening of the exhaust valve is the second in importance of the valve timing events, as opening either too early or too late will cause loss of power.

The exhaust line is above the atmospheric line and at a distance from it equal to the pressure which has to be overcome to expel the gas. On an aircraft engine without a manifold this is only the resistance of the

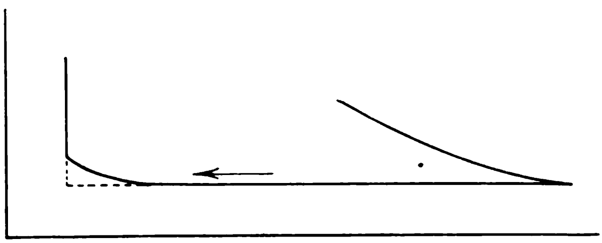

FIG. 23.—Too early closing of exhaust valve.

exhaust valve, exhaust valve seat and housing, and is comparatively small. The closing of the exhaust valve usually takes place at the end of the stroke, or a few degrees past top center. If the valve closed before top center the products of combustion in the cylinder at that time would be trapped and compressed in the clearance space causing a higher pressure at the end of exhaust, as shown in Fig. 23.

Allowing the valve to remain open about 10° P.T.C. permits more of the exhaust gas to get out by taking advantage of the inertia effect of the gas rushing out of the cylinder, as previously discovered. In a six-cylinder engine, all cylinders exhausting into one manifold, one cylinder may be near the end of its exhaust stroke when another cylinder is just starting to exhaust. The high pressure from the second cylinder will cause a slight increase in pressure in the first cylinder, building up a slight terminal-exhaust pressure. This does not always apply in the case of aircraft engines because some do not use manifolds. On large single-cylinder stationary engines, with large straight exhaust lines, the inertia effect of the gas rushing out will tend to create a partial vacuum in the cylinder, lowering the terminal exhaust pressure; but this does not occur on aircraft engines. The closing of the exhaust valve is the third in importance of the valve timing events.

Overall Performance Factors

31. Mean Effective Pressure, Fuel Consumption. It is possible to measure the aggregate effect of all of the foregoing items even though each cannot be separated. All good points cannot be incorporated in one machine as they are sometimes in conflict. The overall performance can be measured, however, and the results expressed in mean effective pressure as a measure of power, and fuel consumption as a measure of efficiency.

Up to the year 1914, when the first report of the "National Advisory Committee for Aeronautics" was written, the highest mean effective pressure reported was 114.4 lb. per sq. in. for the German Daimler engine. The fuel consumption was about .51 lb. per hp. hr. This Daimler engine developed 100 hp. and weighed approximately 4 lb. per hp. Today (1918) the best results are obtained from the Liberty with a mean effective pressure of 116 lb. per sq. in. and a fuel consumption of about .53 lb. per hp. hr.

From the foregoing figures it might be said there had been no improvements in four years. However, it must be remembered that the Liberty engine is approximately 400 hp. and weighs only 2.2 lb. per hp. The power has been quadrupled and the weight per horsepower cut in half. When these points are considered it is remarkable that the mean effective pressure could be maintained.

32. Horsepower Speed Characteristics.—It is not fair to judge one machine at its best speed, but performance as to horsepower and fuel consumption over a range of speeds should be considered. To correctly ascertain the characteristics of an engine a test should be run measuring horsepower against speed. The engine should be loaded by means of a Prony brake or an electric dynamometer, and run at various speeds,

measuring the power for each speed. A curve should be plotted from this data, a typical one being shown in Fig. 24. Such a curve is known as the characteristic curve of the engine and will be similar in shape for every gas or gasoline engine. The power increases directly with the

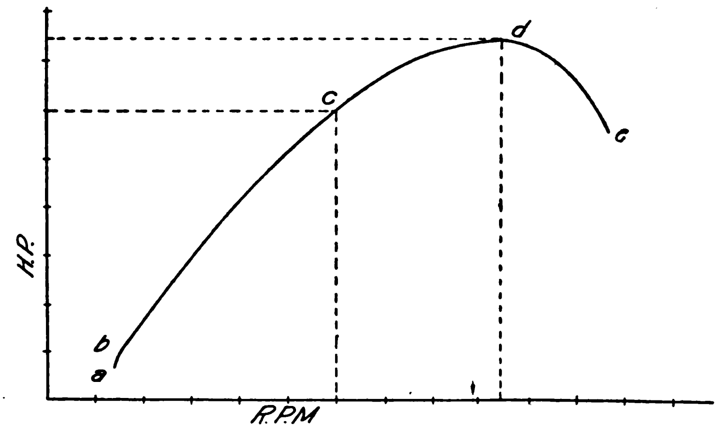

FIG. 24.—Characteristic curve of engine.

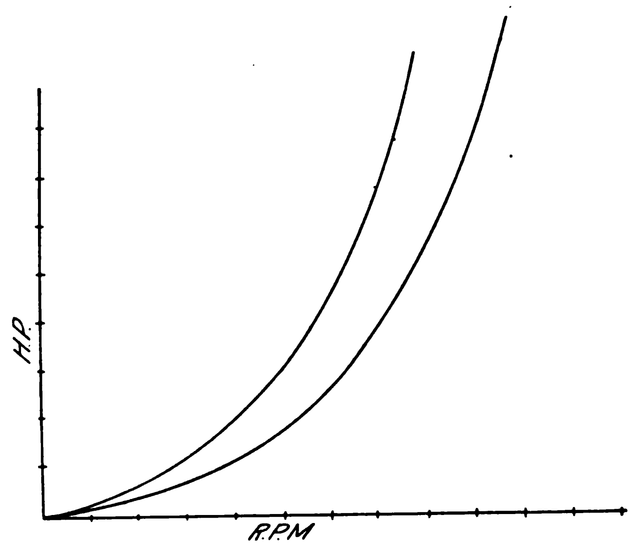

FIG. 25.—Propeller characteristic curves.

r.p.m. up to point *c*, after which further increase of speed causes only a small increase of power to point *d*, beyond which a falling-off of power takes place as the speed is raised. Point *d* is the speed at which the engine should be run to obtain maximum power.

A characteristic curve can also be obtained for an aircraft propeller

by driving it at different speeds by means of an electric motor, measuring the power necessary to drive it and plotting horsepower against revolutions per minute. Such a curve is shown in Fig. 25. All propellers will have characteristic curves of the same general shape. To properly select the correct propeller for any engine it is necessary to plot the propeller curve and the engine curve on the same axes and to the same scale.

Fig. 26 shows an engine curve and three different propeller curves. Curve No. 1 is from a propeller which is evidently too large for the engine, as its curve intersects the engine curve at point a, which is below the best power of the engine. The propeller requires more power to drive it at higher speed then the engine can deliver, so its use would keep the engine

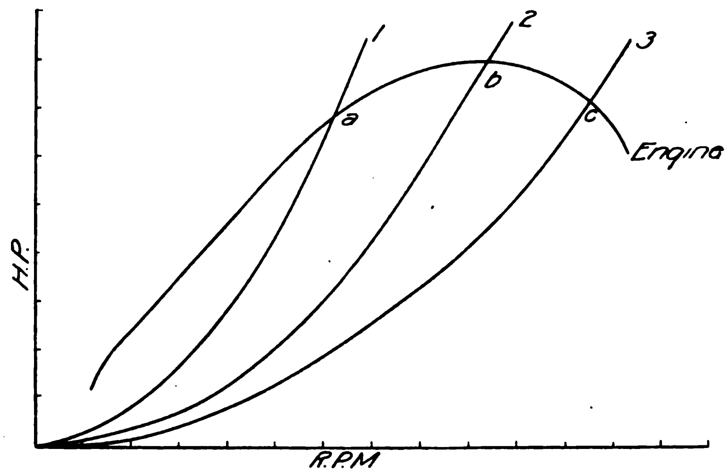

Fig. 26.—Section of propeller for engine.

speed down far below its best speed. Propeller No. 2, is too small as it would allow the engine to run at a speed which is too great for its maximum power. Propeller No. 3, is the correct one to use as its curve intersects that of the engine at point b, which is the point of maximum engine power and at that speed the propeller requires just the power that the engine can deliver.

Speed Limiting Factors

33. Mean Effective Pressure vs. Speed. The next item in the analysis of the horsepower curve is to determine the causes for the change of power with variation of speed. This leads to a determination of mean effective pressure. The horsepower formula derived previously is:

$$\text{Hp.} = \frac{PLAN}{33{,}000}, \text{ in which } P \text{ was the m.e.p.}$$

This formula may be written:

$$P = \frac{(\text{hp.})\ (33{,}000)}{LAN},$$

in which P is the unknown quantity.

From the experimental curve, Fig. 24, the horsepower is known for any given speed. Since for any engine L and A of the formula are known,

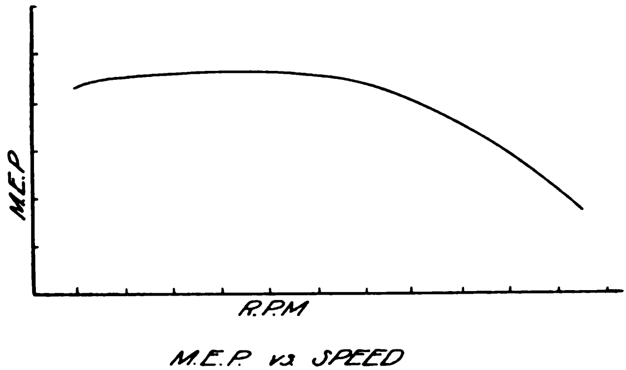

FIG. 27.—Mean effective pressure, speed characteristics.

the only unknown quantity is P. The mean effective pressure can be calculated for every speed and a curve of mean effective pressure against speed can be plotted, as illustrated in Fig. 27.

The volumetric efficiency (real) can be measured for each speed by metering the incoming air, and this can be plotted against revolutions per minute, with results shown in Fig. 28.

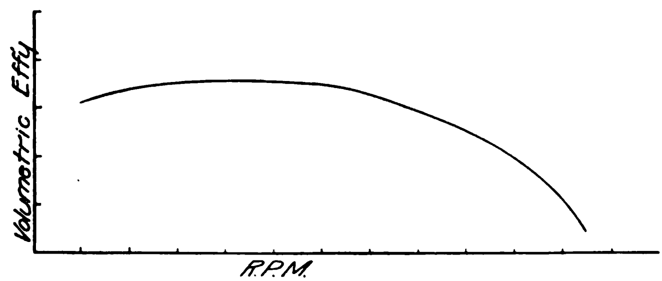

FIG. 28.—Volumetric efficiency, speed characteristics.

In Fig. 29, all the curves are plotted to the same abscissas (r.p.m.) and to different ordinates (hp., m.e.p. and vol. effy.).

The mean effective pressure curve is horizontal as far as speed a, beyond which it begins to fall off. As the speed is increasing the product of mean effective pressure and speed will increase until the point b is reached, beyond which the mean effective pressure falls off faster than the speed increases, and the result is a falling-off in power. The cause of

falling-off of mean effective pressure is seen by examining the volumetric efficiency curve.

When the volumetric efficiency falls, the mean effective pressure drops at the same rate. The falling-off of the volumetric efficiency is due to valve resistances to flow of intake charge, which increases greatly with increased speed. Decrease of charge weight, and also of power, are the result. There is a possibility of the mean effective pressure curve falling off faster than does volumetric efficiency due to incorrect timing and mixture at high speeds and to lack of time for combustion.

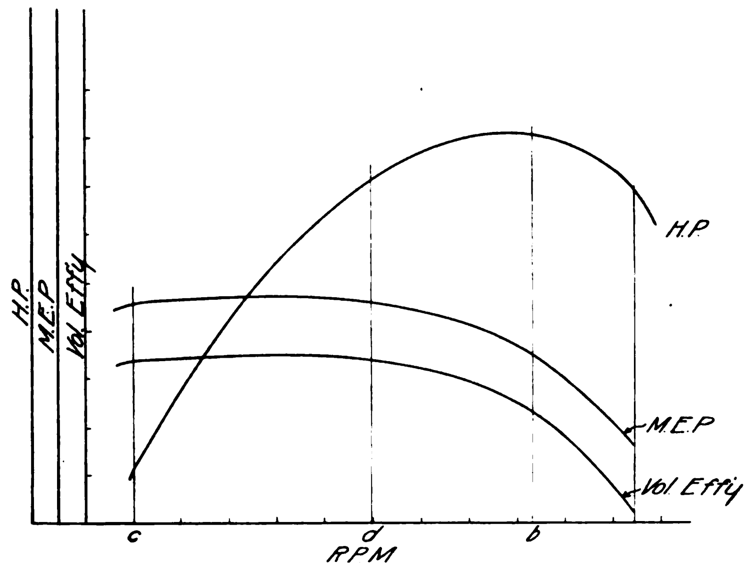

FIG. 29.—Combined speed characteristics diagram.

These former difficulties may be corrected by adjustments but the latter only by change in engine design or structure.

Maximum power will occur when the product of mean effective pressure and speed is a maximum, as at *b*, in Fig. 29. The speed at *a*, Fig. 29, is the speed of maximum mean effective pressure. It is also the point of maximum thermal efficiency and where the fuel consumption per hp. hr. is a minimum.

Inertia and Centrifugal Forces

34. Centrifugal Forces. Two important forces produced in a gas engine are inertia forces and centrifugal forces, and these will now be examined.

Fig. 30 represents a two-throw crankshaft. It is in perfect static balance but is not in running balance. Centrifugal force tends to throw each crankpin away from the center causing an unbalanced couple, and

this tends to produce a rocking of the crankshaft which has to be taken care of by the main bearings in addition to the normal load. Centrifugal force varies with the square of the speed and directly with the weight of the moving parts, so that doubling the speed increases the force four times. In high-speed engines this excessive force may prove injurious. To overcome this centrifugal effect counterweights are added to the

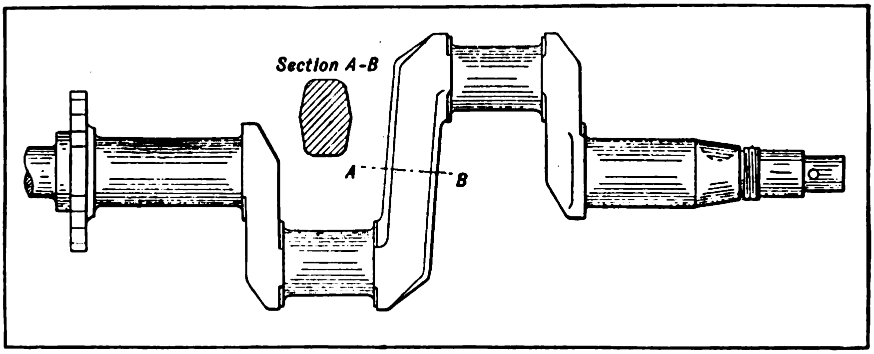

Fig. 30.—Two-throw crankshaft.

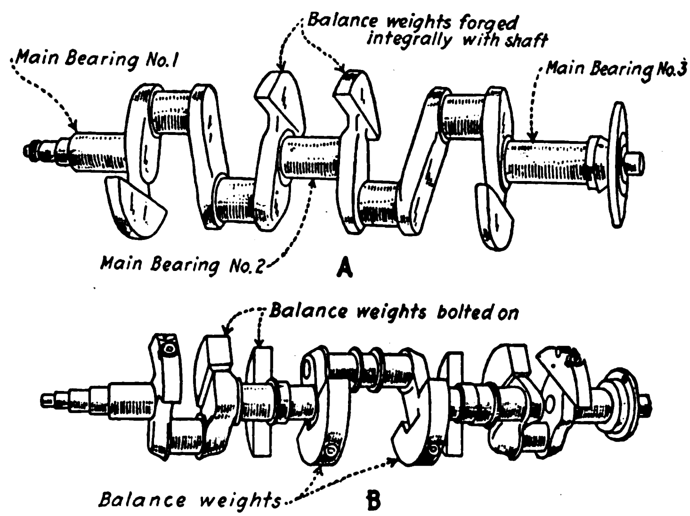

Fig. 31.—Four-throw balanced crankshaft.

crankshaft. Fig. 31 illustrates two four-throw crankshafts with methods of fastening balance weights.

This puts the shaft in perfect running balance, and there is no extra loading on the bearings from this source. It is possible by means of counterweights to perfectly balance centrifugal forces.

35. Inertia Forces. These forces are caused by reciprocating weights. Reciprocating parts of the engine include the piston, piston rings, wrist-

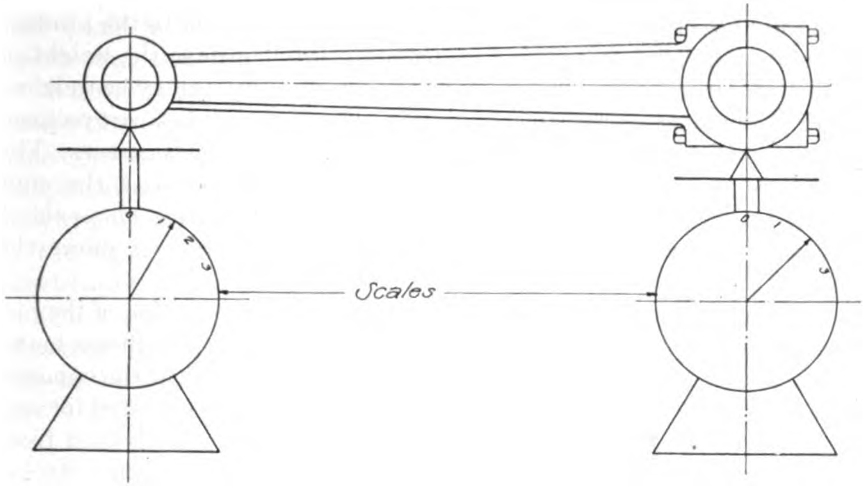

Fig. 32.—Determination of weight of connecting rod.

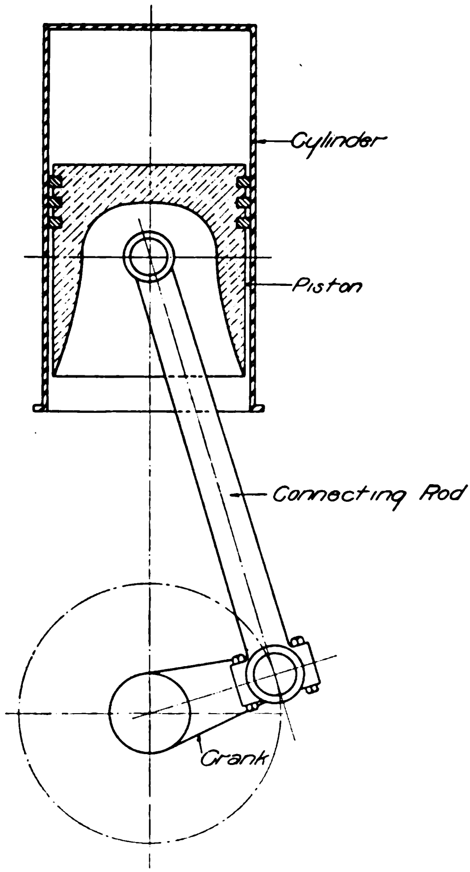

Fig. 33.—Piston and crankshaft assembly.

pins and part of the connecting rod. Since force is equal to the product of mass and acceleration, it is first necessary to determine the weight of the reciprocating parts. The piston, rings, and wristpins may be weighed directly, but since part of the connecting rod has rotary and part reciprocating motion it is necessary to weigh it in a different manner. The connecting rod is supported horizontally on two scales with the ends resting on knife edges as shown in Fig. 32. The reading on scale *A* represents the reciprocating weight of the rod while scale *B* shows the rotating weight.

Before going further into inertia forces, consider the action of the piston during one stroke. It starts from rest (zero speed), reaches a maximum speed at some point of the stroke and comes to rest at the opposite end of the stroke. The velocity of the piston may be calculated for any position of the crankshaft or may be determined graphically and from either result a diagram can be drawn of piston velocity against stroke. Such a diagram shows the maximum velocity not at midstroke but at some point before the middle at the position where the connecting rod and crank make an angle of 90° as shown in Fig. 33. It is evident that the point of the stroke where the velocity is maximum depends on the length of the connecting rod. The longer the rod the nearer the maxi-

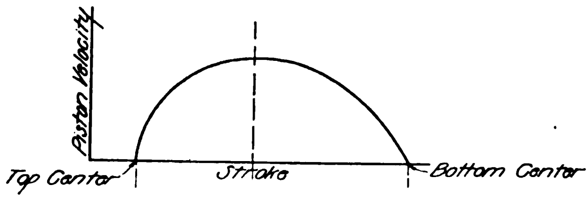

FIG. 34.—Piston velocity diagram.

mum velocity will approach the middle of the stroke, and if the rod were of infinite length the velocity would be maximum at exactly midstroke. From the beginning of its motion to the point of maximum velocity the piston is being accelerated, and from that point on is retarded until brought to rest at the opposite end of the stroke.

When making a graph of piston acceleration versus stroke, it is usual to plot the positive acceleration, or acceleration to bring the piston up to maximum speed, below the zero line because work has to be done on the piston to produce the acceleration. Negative acceleration, or retardation, is plotted above the zero line of the diagram because the piston gives up work in coming to rest.

Fig. 35 is such a piston-acceleration diagram.

The acceleration is zero at the point where the velocity is maximum, and if the connecting rod were of infinite length the point of zero accelera-

tion would be at the middle of the stroke. In that case the acceleration at the start and finish of the stroke would be equal and opposite.

With rods of ordinary length the acceleration is greater at the top center than at the bottom center, Fig. 35. Since force equals mass times acceleration, the inertia force is equal to the product of the mass of the reciprocating parts times the acceleration found in Fig. 35; and since the weight of the reciprocating parts of any engine is constant for every point of the stroke, the inertia-force diagram will be the same shape as the acceleration curve will appear in Fig. 36.

The work in foot-pounds necessary to accelerate the piston is represented on the diagram by the area *A*. This work is considered as negative because it has to be expended on the piston. Ordinates in area *A*

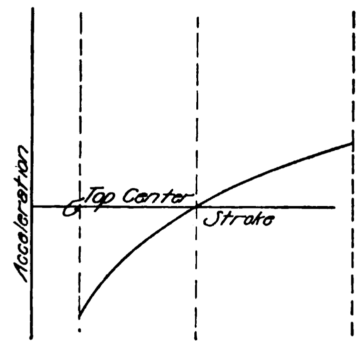

FIG. 35.—Piston-acceleration diagram.

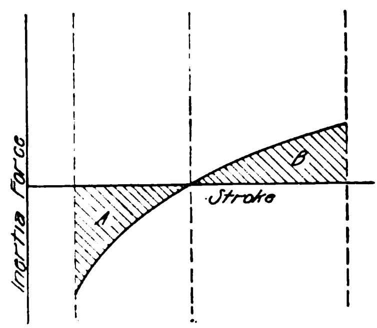

FIG. 36.—Inertia diagram.

are subtracted from the total force developed by the explosion to determine the effective force. The area *B* represents the work given out by the piston when it is being retarded and stopped. This is considered as positive work because it aids the explosive force. Areas *A* and *B* are equal, the work necessary to accelerate the piston being all given back when the piston is stopped. However, due to the angularity of the connecting rod, the inertia force at the top (in starting) is greater than the inertia force at the bottom center (in stopping). No matter what arrangement of counterweights are used these two forces can never be equal when a connecting rod of finite length is used. It is the inequality of inertia forces at the end of the stroke that causes vibration of the engine. This cannot be overcome in a reciprocating engine, although the longer the connecting rods the nearer the two forces are equal and the less the vibration.

To see what effect this inertia force has upon engine operation it is necessary to draw a combined diagram in which force due to gas explosion, and force due to inertia, are combined.

In Fig. 37 there has been drawn a gas-pressure curve for the expan-

sion stroke of an engine, together with an inertia-force diagram for an engine in which the inertia forces are rather small. This would be the case where the speed was low or the reciprocating parts light.

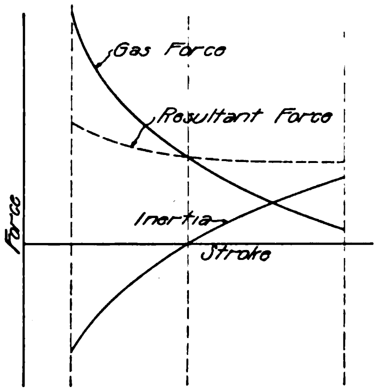

FIG. 37.—Diagram of combined forces.

The resultant force line is obtained by taking the algebraic sum of the gas forces and the inertia forces, for each point of the power stroke. It can be seen that the resultant, or net force acting throughout the stroke, is more nearly constant. It is not a very large force at the beginning, and is even smaller at the end, of the stroke. The effect of the inertia force in this case is, therefore, beneficial. It tends to equalize the irregularities of the expansion stroke by eliminating the effect of the high explosion pressure at the beginning, and to make the force at the start and the finish more nearly equal. This decreases the

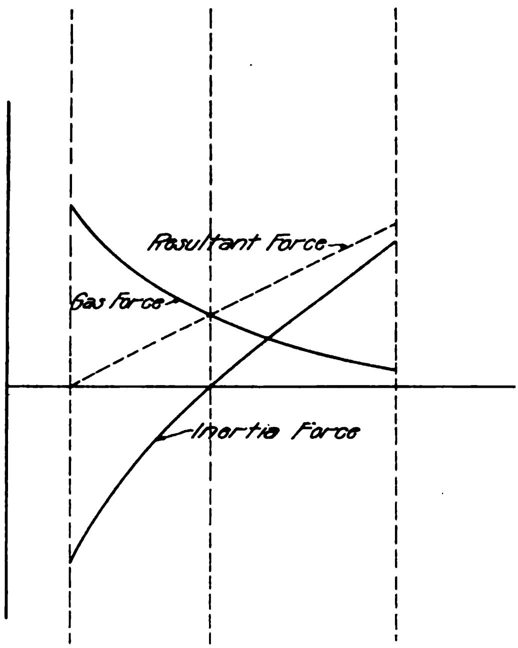

FIG. 38.—Diagram of combined forces, gas force equals inertia force.

wear on the bearings. A heavy pressure at one end of the stroke and a light pressure at the other end would tend to break down the bearings.

Inertia force may be increased in two ways. It varies directly as the weight of the reciprocating parts and as the square of their velocity, and both can be increased up to a certain limit, namely, the point where the inertia force is equal to the maximum gas force. That may be shown on a diagram.

In Fig. 38 the resultant or net force at top center is zero, while at bottom center it is maximum, possibly even greater than that due to the explosion. This would cause such a strain on the bearings that they would soon be destroyed.

36. Balancing of Forces vs. Engine Vibration. Centrifugal force can be balanced, and therefore, causes no vibration; on the other hand, inertia forces cannot be perfectly balanced, and are the cause of vibration. This vibration eliminated the use of single-cylinder engines for aircraft service, and lead to the adoption of multi-cylinder engines, in which one piston going down tends to balance the other piston going up. Even with multi-cylinder engines, however, perfect balance cannot be produced, because of the inequality of the inertia force at the beginning and end of the stroke.

Most aircraft engines are combinations of either four or six cylinders. In the former the cranks are arranged at 0°–180°–180°–0°; and in the latter 0°–120°–240°–240°–120°–0°. These arrangements give the best balancing of forces. It is possible to arrange a four-throw crankshaft at 0–° 180°–0°–180°, but this arrangement will produce couples of force and will cause a rocking of the shaft in the bearings. Cylinders are either four or six in line or a combination of eight or twelve cylinders with *V* arrangement, using the same crankshaft arrangement as in four- and six-cylinder engines. In other words, two opposite cylinders of the *V* use the same crankpin.

Summary of Factors Affecting Thermal Efficiency

37. Mixture Quality. Thermal efficiency varies directly with compression pressure only if certain other conditions are true. The first of these is mixture quality. Mixture may be lean, rich or wet. If lean, it can be detected by back firing through the carburetor; if rich, it can be determined by analyzing the exhaust or reducing the amount of gasoline, and noting the effect on the running of the engine. Wet mixtures may be remedied by heating the mixture or by using a lighter grade of gasoline.

38. Combustion Timing. Another item affecting thermal efficiency, irrespective of compression pressure, is combustion timing. If the ignition is too late or too early it will reduce the power, and hence, thermal efficiency. If the burning is too slow it lowers the efficiency and may be remedied by the use of additional plugs.

39. Throttling. In general, anything affecting mean effective pressure except weight of charge, will affect thermal efficiency. Throttling the intake mixture reduces the volumetric efficiency of the engine and thus decreases the power developed by the engine, as may be seen in Fig. 39. Area *A* represents the positive work, or work produced in the engine cylinder; and area *B* represents negative work. Throttling the mixture will cause an increase in area *B* and a decrease in area *A*. The difference between these two areas represents power produced.

Although it has been previosly stated that variation of weight of charge does not affect thermal efficiency, it is apparent from Fig. 39 that throttling the mixture intake not only reduces charge weight but

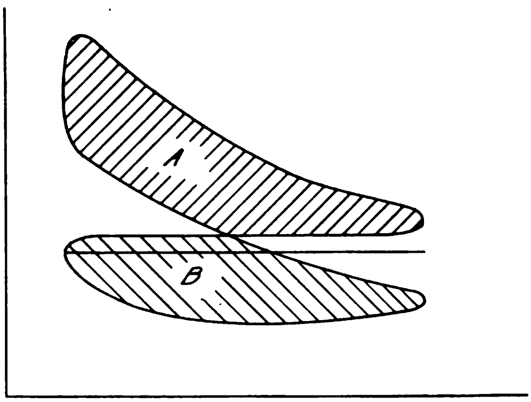

Fig. 39.—Effect of throttling.

also lowers thermal efficiency, for throttling reduces suction pressure, initial compression pressure and final compression pressure. It has been previously mentioned that thermal efficiency is dependent entirely upon final compression pressure.

40. Cyclic Efficiency as a Standard. It is not fair to compare two engines on their thermal efficiency alone. An absolute standard is necessary so that each engine may be compared to this standard. There is such a standard for internal-combustion engines known as the air-card cyclic, or theoretical, efficiency. It is the efficiency the engine would have if it perfectly carried out the possibilities known to be present in the particular cycle or series of operations performed on the fuel. It may be figured for any engine, using the following formula:

$$\text{Theoretical efficiency} = 1 - \left(\frac{P_a}{P_b}\right)^{\frac{S-1}{s}}$$

Where P_a = Pressure before compression.
P_b = Pressure after compression.
S = Exponent of compression varying from 1.33 to 1.406.

It can be seen that the theoretical efficiency increases with increase of compression pressure.

The real or actual thermal efficiency must be found from test. The ratio of this actual thermal efficiency based on indicated horsepower to the ideal, or cyclic, efficiency is known as the diagram factor. It is the comparison of the actual engine to the perfect one and furnishes a measure of the goodness of the former. The higher the diagram factor the closer the actual engine approaches the ideal one.

Internal Temperature Control

41. Temperature Control vs. Continuous Operation. Two divisions of power processes, mixture making and treatment in the cylinder, having been covered, the third, or heat control, should now be discussed.

No matter how perfectly the first two power processes are carried out, the engine will soon stop unless heat control is good. As previously stated, the rate of heat generation is higher in the aircraft engine than in any other type of engine, hence the problem of heat control is very important. Reliability is almost entirely dependent on temperature control, so one cannot know too much about internal temperature or the possible remedies for the troubles incident to high rates of heat generation. Until recently, very little attention has been given to the problem, because it is comparatively new, and, because engineers have been so rushed with problems dealing with metals, tools and production, that little time has been devoted to temperature control.

42. Factors Affecting Internal-temperature Control. In making an analysis from the viewpoint of heat control, everything is dependent on the rate of heat generation. Three things should be considered, namely, the heat generated, the heat path, and the place of final disposition of the heat. Other things being equal, the interior parts of the engine will run hotter, the higher the rate of heat generation. Likewise, the hotter the place of final disposal of the heat, the hotter will the cylinder walls be. As an air film is a poorer heat conductor than a water film, an air-cooled surface will run hotter than a water-cooled one, provided the air film and the water film are at the same temperature. With the same internal and external-temperature conditions, metal temperatures will run higher as the conducting path is low in conductivity, or heat-carrying capacity. The resistance to heat flow varies directly with the length of path in the direction of flow, and inversely as the cross-section of the path at right angles to heat flow. In making a study of the heat control of any engine or engine part, it is as necessary to trace the path of the heat flow as it is to trace the path of the current in an electrical circuit.

Rate of heat generation is a variable quantity dependent on power

and speed conditions. The problem is to furnish heat paths of sufficient capacity to carry off the unusually large quantity of heat which is generated, and to produce uniform cylinder temperatures. This is one of the reasons which necessitates using a number of cylinders on a high-powered engine, instead of one large cylinder.

43. Temperature Control vs. Cylinder Size. As previously stated, every inch added to cylinder diameter increases the complexity of the problem. In American practice, 5 in. has been found the maximum practical cylinder diameter for aircraft engines. In explaining this limit, it is well to consider that the amount of heat generated is dependent on the weight of fuel burned; which, in turn, is dependent on the volume. The volume varies as the cube of the dimensions, assuming the speed to remain constant. An occasional foreign engine may be found with a cylinder diameter larger than this, but analysis will show that the rate of heat generation is not as high as in American practice, due principally to the use of lower compression. It should be remembered that the ability to dissipate heat from the cylinder depends upon the area of the cylinder walls; and that area varies only as the square of dimensions. Therefore, when the dimensions of a cylinder are increased, the amount of heat generated increases much more rapidly than the surface available for its dissipation. There is no reason why the employment of new designs, other materials, or new methods of cooling may not permit the use of larger cylinder diameters at some future time, but the 5-in. limit may be said to represent present practice.

44. Temperature Control of Fixed and Moving Parts. To convey the heat from the outside of the cylinder walls to the point of final disposition, either air cooling or water cooling may be used. In general surfaces which are air-cooled run hotter than those which are water-cooled. The efficiency of air cooling depends on the thickness of the air film, and the reduction of this film requires considerable power. To furnish enough air for this purpose in the Renault engine, from 15 to 20 per cent. of the total power of the engine is used; while in the Gnome, about 8 per cent. is required, to rotate the cylinders against air resistance. In an air-cooled engine, the cylinder walls do not run as uniform in temperature as do those of water-cooled engines. In comparing air cooling with water cooling, it is interesting to note that approximately 52 cu. ft. of air is required to accomplish the same cooling effect as 1 pt. of water. Naturally, then, the power required to supply the cooling water is much less than that for supplying air to produce the same results. With water cooling, it is assumed that all the heated metal will be in contact with water, but this does not always happen. Sometimes, due to poor circulation, the water in contact with a portion of the metal area will boil. This means that the heat must be conducted through steam, which is no better conductor than air. When a hot boiler tube, or plate,

runs dry for a minute, a bulge or blow-out results. In a similar manner, harmful metal effects are produced in the engine. A hot dry spot, or steam spot, results in lower charge weight and, sometimes, in preignition.

In designing a water jacket, it is essential that no spots of sluggish circulation be allowed to exist, as they will result in steam pockets. It is also important that the water outlet from the jacket be at the highest

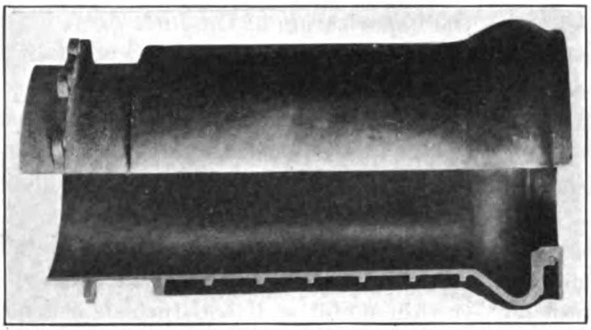

FIG. 40.—Cross-sectional view of Curtiss V2 showing flanges.

point, so that there will be no tendency for the accumulation of steam or air. Between its inlet and outlet, the water may take any path through the jacket, but will naturally choose that of least resistance, usually a direct line from inlet to outlet. To assist in diverting the water from this direct line, flanges are usually provided, at intervals, on the outside of the cylinder walls. These flanges not only help in directing water circulation around the cylinder, but also increase the strength

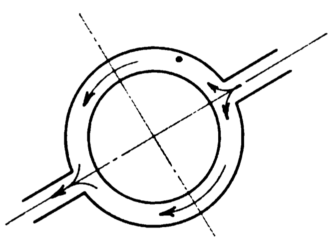

FIG. 41.—Water entering jacket at right angles.

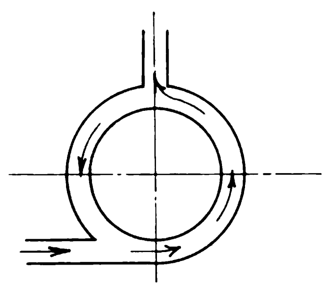

FIG. 42.—Water entering jacket tangentially.

of the cylinder wall to a certain extent. Fig. 40 shows a cross-sectional view of a Curtiss V2 cylinder which is provided with these flanges, or ribs. Another method of providing uniform circulation, is to have the water enter the jacket tangentially, thus setting up a whirling motion around the cylinder, from the start. In most cases, however, the cooling water enters the jacket radially, the difference between the two methods being shown in Fig. 41.

The more rapid the circulation of the water in the jacket, the cooler the engine will remain. It is desirable, therefore, to allow just as small a jacket space as possible, but it should not be less than 1/8 in. With less space, the circulation might be impeded by a dented jacket, or, by scale deposits on the jacket walls caused by impurities in the water. Although it is desirable to keep the temperature of the cylinder reasonably low, no part of the combustion chamber should be allowed to become so cool that it will interfere with the vaporization of the fuel.

When considering engine parts from the viewpoint of heat control, they may be grouped into three classifications:

1. Directly-cooled fixed parts, such as cylinders, crankcase, etc.
2. Indirectly-cooled fixed parts, such as valve caps, spark plugs, etc.
3. Indirectly-cooled moving parts, such as piston, valves and crankshaft.

Every part of the engine should be considered in detail, but only a few of the most important can be taken up here. The cylinder is given first consideration. A thin metal wall will furnish a good, short heat path, and will remain cool as long as water is in contact with it. The wall will become red hot in a very short time after the water is lost, and the thinner it is, the more quickly will it heat. Once overheated, the metal will take a permanent set, and, if the heated spot is on the surface, the cylinder is ruined.

If the metal is unequally heated, it will undergo unequal expansion. Air-cooled engines suffer most in this respect; those with circumferential ribs, expanding out of vertical, and those with vertical ribs, expanding out of round. It is essential that the cylinder head be kept cool, especially in the vicinity of the valve seats, which, otherwise, might become distorted, causing the valves to leak.

The exhaust valve becomes very hot, as it is heated on both faces, and on a portion of the stem, by the burning gases. The burning of this valve is one of the most troublesome features of aircraft engines, or any other engines which have a high rate of heat generation. Most attempts to correct this fault have been along the line of selection of material, trying to obtain one which oxidizes slowly and retains its strength at red heat. Tungsten steel has been the most successful in these respects. Heat can leave the exhaust valve only past the seat and along the stem. Since the valve is on its seat more than half the time, it might be expected that considerable heat will leave by that path, and that the cooling could be improved by bringing the water as close as possible to the valve seat. As a matter of fact, however, very little heat passes from the valve to the seat, because of the poor thermal joint between them. The heat which leaves by the stem must be conducted to the guide, and thence to the cylinder head, and the cooling water. It is apparent that the water should circulate as close as possible to the exhaust valve-stem guide. To con-

duct most of the heat from the valve through the stem, it is essential that sufficient stem section be provided. A thick stem alone does not solve the problem, for, if the head is too thin, the heat cannot get to the stem, as shown in Fig. 43. Valve No. 1 in this figure has a stem of comparatively small diameter *d*, while valve No. 2 has a stem whose diameter is about 2½ times *d*.

It will be noticed, also, that valve No. 2 has a large fillet, while No. 1 has hardly any. Both valve stems were immersed in beakers of water, and a blow torch applied to the head of each. No. 1 soon became red hot, almost to the water's edge, but the water remained cool. No. 2 did not become hot enough to melt a piece point of low-melting solder placed upon it, but the water boiled. This experiment shows that

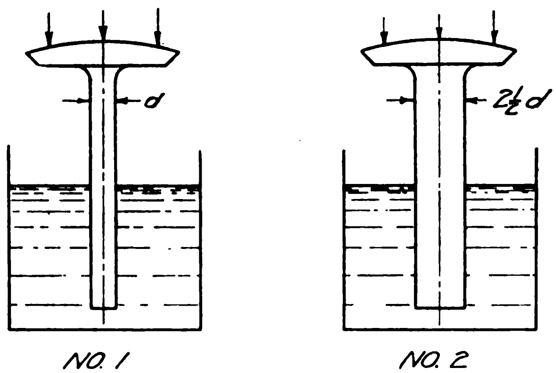

FIG. 43.—Valve experiment.

the heavy stem conducted the heat from the head, to the water, while the light stem did not. A heavy stem is of no value, however, unless the heat can be dissipated from it. On some engines, the valve-stem guides are not cooled along their entire length, nor is there sufficient metal in them to carry the heat to the water-cooled parts. It is evident that such guides are designed without reference to heat dissipation, but even a well cooled guide is insufficient unless there is thermal contact between it and the stem. If the fit between stem and guide is a loose one, there will be an insulating film of air or hot gasses, between them. The best way to provide for heat flow at this point is to have a thermal bridge of oil in the clearance space. Spring stuffing boxes would help to retain this oil, and their adoption may be expected in the near future. The ordinary type of stuffing box, as used on steam engines, will not serve because of its tendency to jam.

The problem of heat control on the inlet valve is not difficult, for the cool incoming charge tends to keep the temperature within reasonable limits. But this is attained at the expense of heating the fuel charge, and results in lowered volumetric efficiency.

The spark plug is an example of an indirectly-cooled fixed part, with inadequate means for heat dissipation. The heat must be conducted through the threads, to the cylinder, but the thermal contact is poor. Plugs are often provided with ribs which increase the surface exposed to the air, and aid in dissipating the heat.

The piston is one of the most important parts of the engine to be examined from the viewpoint of heat control. Those used on the early aircraft engines were of the automobile design, but with the thickness of head and skirt cut down to reduce metal weight. In some cases, holes were bored in the skirt for the same reason. Steel was tried as a piston material but, for proper strength, sufficient metal for satisfactory heat conduction was not provided, and the pistons burned through in a short time. This was considered a necessary evil, but, when additional trouble was experienced from excessive carbon formation and insufficient lubrication, search was made for another material. The overheating of these thin steel pistons is due to the following reason; the same amount of heat is given to the piston head as to any other equal area of the combustion chamber, and, as the piston is not water-cooled, it is obvious that it will tend to overheat. The heat absorbed by the piston head can be dissipated only to the air in the crankcase below, or by conduction to the cylinder walls. The amount absorbed by the air in the crankcase is negligible, and the one path to consider is that from the head to the skirt, and thence, through the oil film, to the cylinder walls.

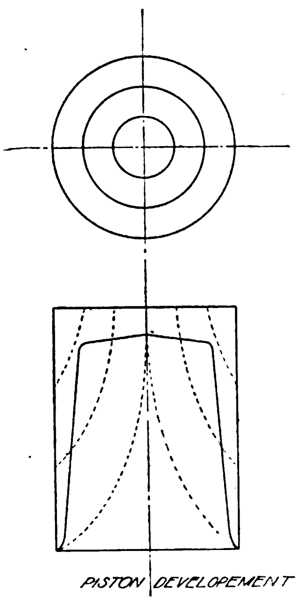

FIG. 44.—Piston development.

A piston constructed as shown in Fig. 44 will run at nearly uniform temperature, as an equal heat path from head to bottom of skirt is secured by making use of all of the skirt for the dissipation of the heat to the cylinder walls. The head may be imagined as divided into three equal areas, as shown; two rings, 1, and 2, and a circle, 3. The skirt, in a similar manner, is divided into three equal lengths. In a correctly designed piston, all the heat absorbed by area 1 on the head, should be dissipated to the cylinder wall in zone 1 on the skirt. Similarly, all the heat from head areas 2 and 3, should be dissipated by skirt zones 2 and 3, so that there should be no heat left in the bottom of the skirt, to be dissipated to the cylinder walls. Therefore, to furnish an adequate heat path, the thickness of the head should increase toward the head end because more

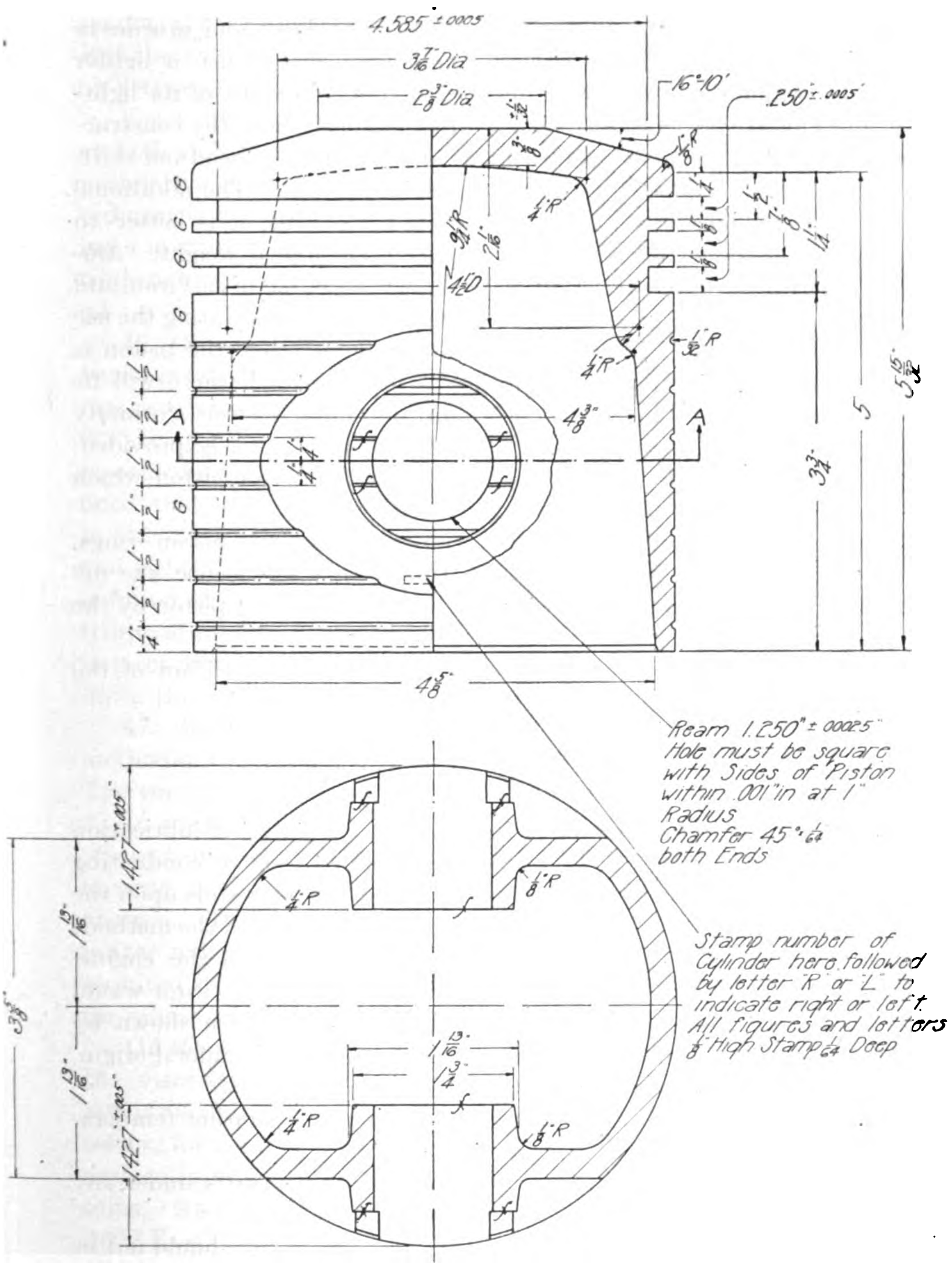

FIG. 45.—Sectioned Liberty piston.

and more heat is carried away by the cylinder walls. This design requires much more metal than the thin steel piston described above, and, in order to keep weight at the minimum, it was found necessary to use a lighter material. Aluminum has proven very satisfactory, because of its lightness, and now is very generally used. Most pistons follow the construction outlines above, a generous fillet being allowed between head and skirt. Fig. 45 is a sectional view of a Liberty engine piston. The additional metal naturally increases weight, but, of the two evils, it is better to provide an adequate heat path at the expense of added weight. Aluminum has a high thermal conductivity, almost twice that of cast iron, and for equal temperature changes, will expand more, necessitating the use of greater clearances. This tends to cause slapping when the piston is running cold, and if sufficient clearance is not provided, there will be binding and seizing when hot. The thin aluminum pistons, formerly used, gave trouble for this reason. But if sufficient metal is provided, as described above, the piston does not get as hot as an iron piston, which fact tends to equalize the expansion in the two cases.

Overheated pistons cause carbonization of oil on the piston rings, causing them to stick in the grooves. Hot pistons also cause the decomposition of some of the oil which is thrown inside the piston by the revolving crankpins.

Evidence of hot pistons can be seen in the smoke blown out of the exhaust ports or the breather tubes.

Lubrication

45. Lubrication vs. Qualities of Lubricant. The object of lubrication is to decrease the loss of power, lessen wear, and to aid in conducting generated heat from all bearing surfaces. The oil used depends upon the type of engine, the quality and characteristics of the oil, and the methods and adjustments of lubrication and operating conditions of the engine.

Early in the war it was supposed that no oil other than castor would give satisfactory results in aircraft engines, but it has been shown by experiments, that any oil, whether of animal, vegetable or mineral origin, which satisfies the three following requirements may be used.

1. The viscosity must be maintained at engine operating temperatures.

2. The oil must not decompose at operating temperatures under any conditions.

3. The oil must not react chemically on engine parts; it should not be acid.

Castor oil was not found to be superior to mineral oil for aircraft engines. It maintains its viscosity within the range of operating engine temperatures no better than a good grade of mineral oil, although

it does retain its power of adhesiveness or stickiness better, and for this reason, is used almost exclusively on rotary engines, such as the Gnome. But this same feature of stickiness is of disadvantage in an ordinary line or V-type aircraft engine, as it tends to gum the piston rings.

For a time it was the practice at Naval air stations to use a good mineral oil, such as Mobil *B*, mixed with from 10 to 50 per cent. castor. A peculiarity of castor oil is that it will not mix with mineral oil under ordinary conditions. However, methods have been found of accomplishing a mixture of the two, and many oils which are now sold under special trade names, are nothing more than a combination of castor and a mineral oil.

46. Oil Consumption vs. Type of Engine. The oil consumption varies greatly on various types of aircraft engines. On the Liberty, the rate is approximately 0.03 lb. per hp.-hr. On the Gnome, it runs about 0.25 lb. per hp.-hr., or almost ten times that of the Liberty. The rate of consumption on the Gnome is high because the oil can be used only once, that supplied to the bearings and cylinder walls being thrown out to the cylinder head by the centrifugal force due to cylinder rotation, and either burned, or lost out the exhaust valve. An additional reason is found in the fact that the Gnome, being air-cooled, runs at a higher temperature, and hence, requires more oil to cool the bearings. On all non-rotating engines the oil can be used over and over again, which cuts down the consumption materially.

47. Bearing Lubrication. Bearing lubrication is dependent on the method of oil supply, bearing clearance, and oil temperature and pressure. The various methods of supply will be discussed under "*Engine Details.*"

It is only natural that some systems of lubrication are much more efficient and satisfactory than others. In aircraft engines much larger bearing clearance is allowed than is usual in automobile or stationary engines. The two principal reasons for this are: aircraft engines run hotter and more allowance must be made for expansion; more oil is required to carry away the additional heat, and space must be allowed for a heavier film on the bearing.

Oil temperature must be considered in designing an oiling system, for the viscosity decreases with rise in temperature. The oil should be warm enough to flow freely, but it must not be so hot as to lose its viscosity, for it must retain sufficient body to maintain a film on the bearing surface in order to efficiently perform its lubricating and cooling functions. As a general rule, oil should not be allowed to run hotter than 160° F.

The oil is supplied to the bearings under pressures which are considerably higher than those employed in engines of other types, and which range between 15 and 80 lb. per sq. in. Cool oil at comparatively high pressures gives the best results.

48. Aircraft Engine Oil Specifications. It is not the purpose of this course to describe the specifications, and methods of testing of oil in detail, but some essential points should be mentioned. Viscosity is one of the most important factors to be considered in selecting a lubricating oil, and therefore, the viscosity test is of great importance. The term *viscosity* is applied to the resistance of a liquid to flow, and is really a measure of the so-called *body* of the liquid. Molasses has a high viscosity, while water has a low, because water flows more freely than molasses. Viscosity is a relative value, and various instruments are in use for measuring it. They are called viscosimeters. The one most commonly used in this country is the Saybolt viscosimeter, shown in Figs. 46 and 47.

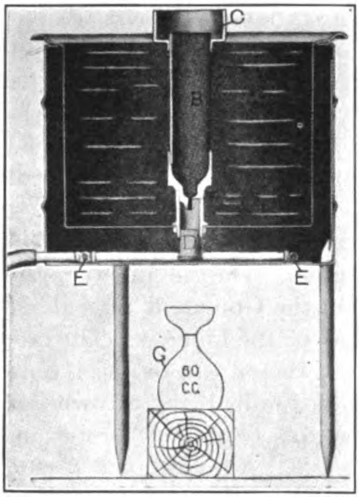

FIG. 46.—Saybolt Universal viscosimeter.

Viscosity is expressed as the number of seconds required for a definite volume of liquid to flow through a standard orifice. Readings may be taken at any temperature, but it is essential, when two or more oils are to be compared, that the tests be made at the same temperature. The viscosity test, and all other oil tests mentioned, are conducted according to the methods of the American Society for Testing Materials. The viscosity required by Government specifications for aircraft-engine oil, Saybolt standard, 212° F., is:

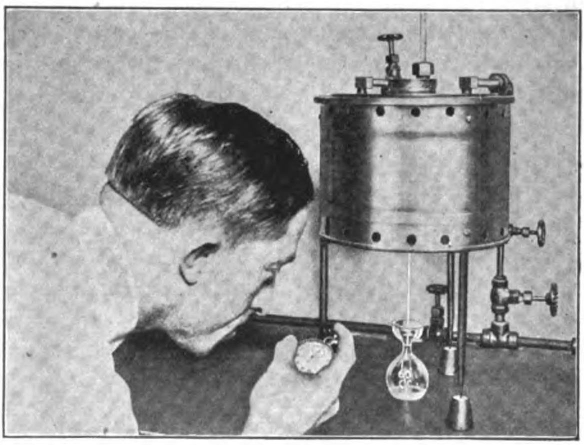
FIG. 47.—Saybolt viscosimeter.

High specific gravity oil....................	70 to 75 sec.
Low specific gravity oil....................	85 to 90 sec.

From these figures, it is apparent that the Government requires heavy oils to be less viscous than light oils.

The pour test, or cold test, of an oil is the lowest temperature at which the oil will pour. This test does not show the lubricating qualities of an oil, but rather, its adaptability to unusual temperatures that may be encountered. A good aircraft-engine oil should pass the following pour test:

High specific gravity oil..................	not over 15° F.
Low specific gravity oil..................	not over 40° F.

The *flash point* of an oil is the lowest temperature at which the vapor arising from it will ignite, without setting fire to the oil itself, when a

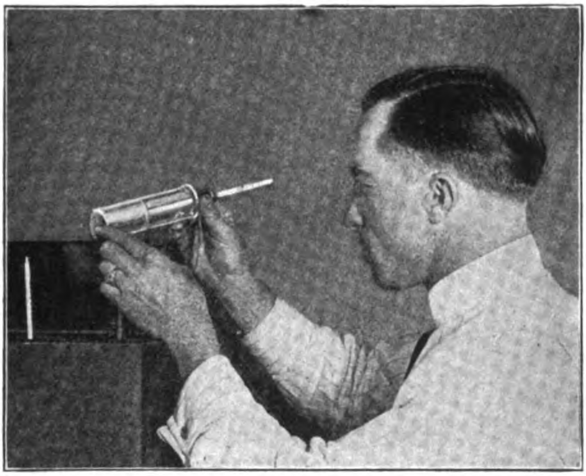

Fig. 48.—Pour test.

flame is passed quickly over the surface of the oil in a test cup. The oil should have a flash point of over 350° F. in a Cleveland open cup.

The fire test is conducted in a manner similar to that employed in the flash test. The *fire point* is the lowest temperature at which the oil itself will ignite, under the same conditions. It is always higher than the flash point, usually by about 60° F. in aircraft-engine oils, but is not as important as the flash test in judging a new oil.

The carbon test involves the determination of the amount of fixed carbon in the oil. This may be accomplished by distillation in a standard flask under prescribed standard conditions. Signal Corps Specifications No. 3501 states that the test by the Conradson method should not show a residue of over 1.5 per cent. The carbon must be loose and

flaky, and must break up easily in the flask. This fixed carbon must not be confused with carbon deposit. In commercial oils, the carbon residue increases nearly in proportion with the increase in viscosity, being lower in the very light oils. The carbon residue which an oil contains does not necessarily indicate the relative amount of carbon deposit which will occur when the oil is used in an engine cylinder, for carbonization is largely influenced by the quality of the oil, its viscosity and flash point, and by piston leakage.

For the emulsion test, 1 oz. of oil is placed in a standard 4-oz. sample bottle with 1 oz. of distilled water. The mixture is heated to a temperature of 180° F. and then shaken vigorously for 5 min. After standing

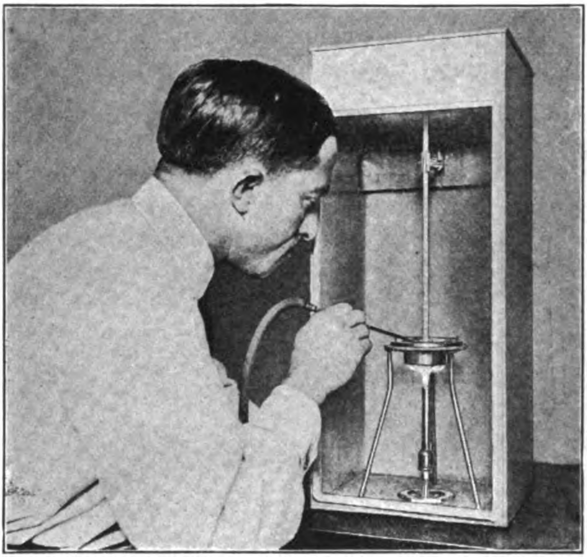

FIG. 49.—Flash test.

1 hr., the oil must be clear, and of the same color as before the test. All of the water must have settled, and must appear only slightly cloudy.

Gravity tests of oil are usually made with the Baumé hydrometer. The density of the oil is read with this instrument, at a temperature of 60° F. Gravity is of no great importance in judging the qualities of a lubricating oil.

Color test is usually made by the Lovibund method, but color does not show the quality, nor the suitability, of an oil.

The oil must be neutral in action, and must not show the presence of moisture, sulphates, soap, resin or tarry constituents, which would indicate adulteration or lack of proper refining.

49. Contamination of Oil. When a cold engine is started, some of the mixture is condensed by the cold cylinder walls, and runs down past the

piston rings into the crankcase, where it mixes with the lubricating oil, and lowers the viscosity of the latter. After the engine runs for a time, and warms up, this gasoline and kerosene in the oil will evaporate, and the oil will regain its original viscosity, to a large extent. The lighter the grade of gasoline used, the greater will be the amount of unvaporized fuel to run down into the crankcase, and consequently, the greater will be the dilution of the crankcase oil. Fig. 50 illustrates the result of a test to show the effect of gasoline on crankcase oil. Samples of the oil are taken from the crankcase at intervals of about 20 min., and their viscosity tested against the time of operation.

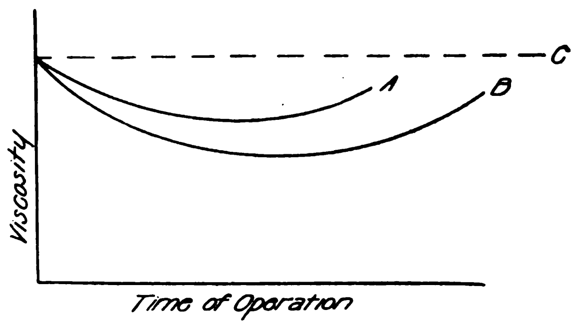

FIG. 50.—Effect of gasoline on crankcase oil.

Assume the test to be started with an oil of viscosity *C*. The ideal case would be as indicated by the dotted line, *C*, which shows maintenance of unvarying viscosity throughout the test. Curve *B* illustrates the variation in viscosity of the crankcase oil during a test when 68° Bé. gasoline is used. Curve *A* illustrates a similar test with 86° Bé. gasoline. The difference is at once apparent. The viscosity of the oil is not decreased as greatly when the lighter gasoline is used. With this grade of fuel, the condensation will not be as great as with the lower grade, hence the viscosity of the crankcase oil will not be lowered to such a degree. Also, with this lighter gasoline, the crankcase oil will regain its viscosity much sooner, because the fuel vaporizes at a lower temperature.

Burned oil which blows past the piston rings, also contaminates the crankcase oil. The higher the engine temperature, and the poorer the grade of oil, the more rapid will be the decomposition of the oil.

50. Recovery of Used Oil. It is a general air-station practice to drain the oil from engines after about 8 or 10 hours operation. This oil may be reclaimed for further use, and will prove to be as good as fresh oil. The process may be repeated several times on the same oil. Oil-reclaiming apparatus may now be purchased ready-built, or a simple outfit constructed to meet the requirements. The principle of operation consists in running steam through the oil for about half an hour, to drive off the kerosene. Two ounces of soda ash for each gallon of oil is added,

and steam again run through the mixture. The soda ash combines physically with the carbon of the burned oil. The mixture is allowed to stand for several hours, and then decanted.

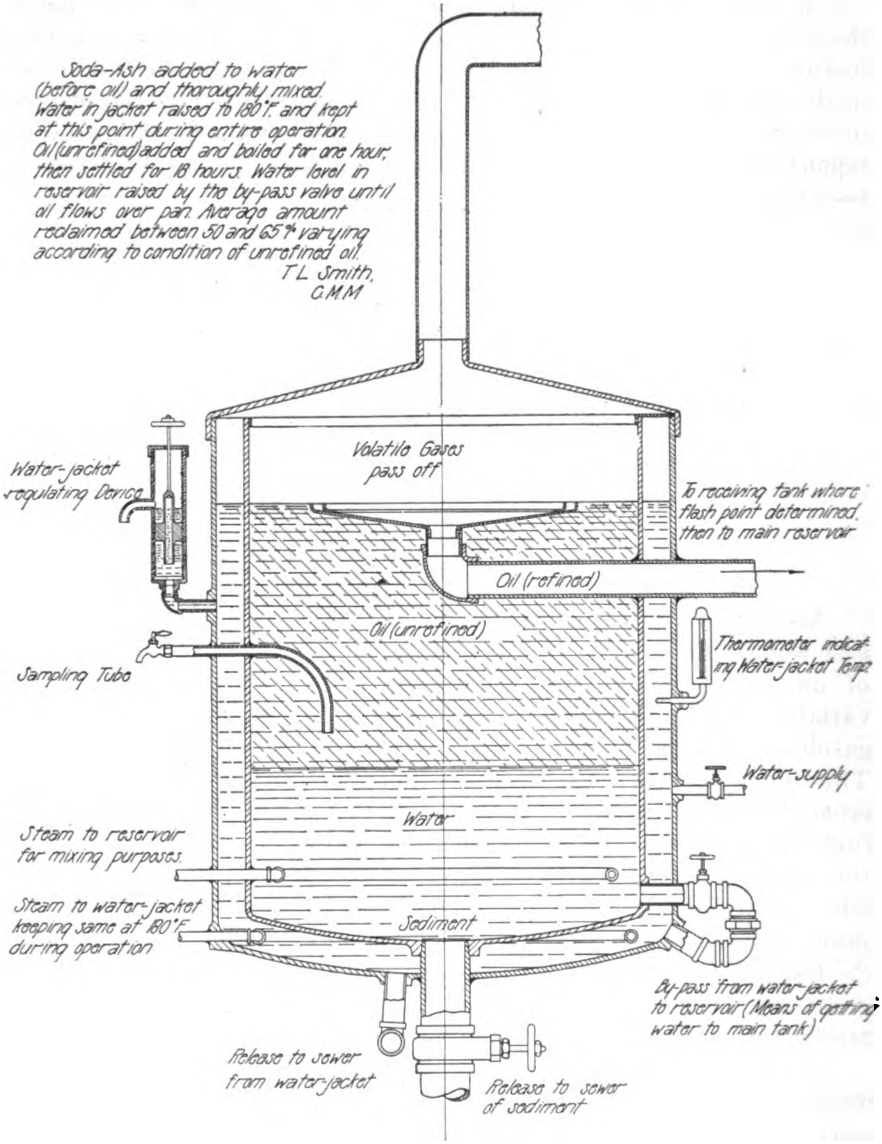

FIG. 51.—Cross-sectional view of home-built oil reclaimer.

Typical Construction

51. Forms and Arrangement of Parts. The form and arrangement of parts in an aircraft engine, from the standpoint of design, construction,

and kind of metals used, has a direct bearing on the weight per horsepower, reliability and adaptability. This subject is equally as important as other parts of the course, but it will be treated for a limited time only, as information on these points is easily obtained from other sources. The object of this work is to advance the proper point of view, leaving to the student the collection and correlation of facts.

52. Design and Construction of Parts vs. Duty Performed. Each part of the engine must be designed and constructed to perform certain specific functions or duties. For example, the primary function of the piston is to act as a means of transforming heat energy or power, as developed by the expansion of the gas, to mechanical work for final delivery, through the connecting rod, to the crankshaft. The minor or secondary functions are, ability to dissipate the heat received during the combustion of the mixture, and maintenance of cylinder compression. It is evident, then, that in designing an engine part, it is very important to consider carefully all duties of the part. In design and construction of aircraft engines, a factor of prime importance, consistent with reliability and adaptability, is increase of power, and reduction of weight per horsepower.

53. Number of Cylinders, and Arrangement. The method of determining the most desirable arrangement and number of cylinders, other things being equal, is to compare the various types of engine construction on a basis of weight per cubic foot of displacement. This basis is an indication of the ability of the designer to so arrange the cylinders that the greatest displacement and maximum horsepower are obtained, with specified engine dimensions. The discussion of weight per horsepower has been made entirely from the standpoint of distribution of metal weight, eliminating factors of speed and mean effective pressure. The weight per cubic foot displacement for various engine types is found by the use of the following formula:

Formula

$$W' = \frac{W \times 1{,}728}{LAN}$$

where, W = Weight of engine dry
L = Length of stroke in inches
A = Piston area in sq. in.
N = Number of cylinders
W' = Weight per cubic foot of displacement.

Example. By substituting in the above formula the proper values for the Liberty engine, the following result is obtained:

$$W' = \frac{820 \times 1{,}728}{7 \times 19.63 \times 12} = 857 \text{ lb. per cu. ft. displacement.}$$

In discussing engine weight, the first type to be considered is a single-cylinder vertical engine. One method of increasing the horsepower, factors of speed and mean effective pressure eliminated, is to increase the cylinder diameter, however, the practical limit to cylinder diameter in aircraft engines is about 5 in. The logical method, therefore, of increasing the power is to add more cylinders. The addition of one cylinder doubles the horsepower of the engine and, at the same time, decreases the weight per horsepower. The weight per cubic foot displacement is likewise reduced, as the crankcase is lightened by eliminating two ends as shown in Fig. 52. The dotted lines in the illustration represent the

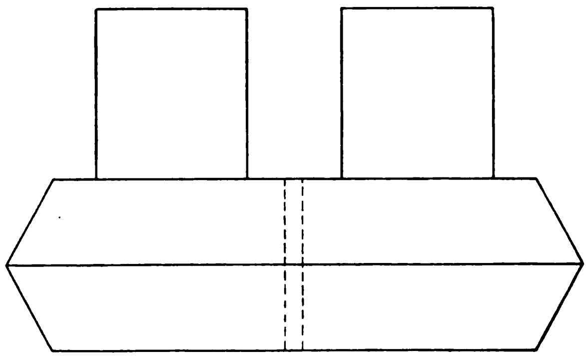

FIG. 52.—Effect of cylinder multiplication on unit weight.

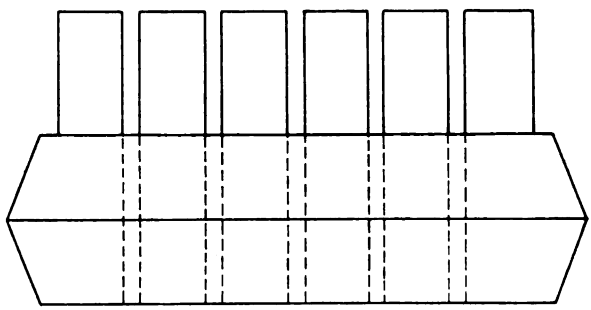

FIG. 52A.—Effect of cylinder multiplication on unit weight.

two crankcase ends which are eliminated by the addition of another cylinder. Fig. 52A shows a further weight reduction by the addition of more cylinders. This does not mean that the engine weight is reduced in proportion to the number of cylinders added, as the rigidity and strength of the case must be maintained. The addition of cylinders necessitates the use of various strengthening members such as ribs and webs, and a heavier casting for the case itself. Some of the elements of a single-cylinder engine, however, such as the carburetor, magneto, and similar assemblies, need not be duplicated, and this affords another source

of weight reduction. By the addition of cylinders, the weight per horsepower is reduced, and this condition holds true until a maximum of six cylinders in line is reached. With more than six cylinders in line, the weight is again increased because a stronger, and consequently heavier, crankshaft and crankcase must be used. The following table, based on marine-engine practice, illustrates the decrease in weight per cubic foot displacement by the addition of cylinders.

TABLE III.—WEIGHT-VOLUME RATIO WITH ADDED CYLINDERS

No. cylinders	Wt. of engine	Lb. added	Vol. in cu. in.	Wt. per cu. in. displ.
1	472	0	472	1.00
2	626	.154	944	0.66
3	716	90	1,416	0.51
4	806	90	1,888	0.43
5	896	90	2,360	0.38
6	986	90	2,832	0.35

In the above table, the weight-volume ratio of unity was used for the single-cylinder engine, merely as a basis for comparison. An evidence of the increase in weight per cubic foot displacement from 6 to 8 cylinders, is shown in the figures of the German Mercedes engine, in which the 6-cylinder engine weighs 1,182 lb. and the 8-cylinder, 1,293 lb.

To increase the horsepower, cylinders may be added radially, in star arrangement. On this type, the weight per horsepower and weight per cubic foot displacement are reduced to an even greater degree than in the cylinder-in-line type, due to compact arrangement. Nine is usually the limit of cylinders in radial multiplication.

A combination of the longitudinal and radial multiplication of cylinders has been successfully employed. Several banks of the radial cylinder arrangement are built on the same crankcase and use the same crankshaft. This is the lightest form of internal-combustion engine, but has many disadvantages due to difficulties in cooling and lubrication.

54. Cylinder Arrangement vs. Reliability and Adaptability Factors. The various cylinder arrangements should be considered from the viewpoint of reliability, cooling, lubrication, performance and adaptability. The vertical cylinder-in-line type has been closely adhered to in German practice. The Hall-Scott engines, in American practice, also have been of this type which offers the lowest head resistance, together with simplicity of lubrication and cooling.

On the other hand, the torque is not as uniform as that of the *V*, or rotary types, and the problems of engine balance is more difficult to handle.

German designs included a vertical cylinder-in-line engine, having

inverted water-cooled cylinders, for which only two advantages are apparent, *i.e.*, increase of the pilot's visibility, because of the lowered position of the engine, and the benefit of having the cool circulating water introduced at the hottest part of the cylinder, surrounding the combustion chamber. The lubrication of this type of engine did not present the expected problem, and gave little or no trouble.

The horizontal-opposed type with two cranks at 180 degrees, in spite of its excellent balance, did not prove adaptable to aircraft work because the power required necessitated the use of such large cylinders that the addition of a flywheel was necessary in order to maintain the steadiness of motion demanded by the propeller. The Darracq, 1910, shown in Fig. 53, was an example of this type.

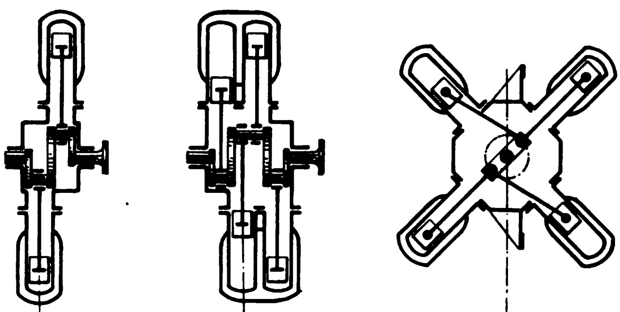

FIG. 53.—Two-cylinder horizontal-opposed Darracq engine.

This design was also built with four horizontal cylinders on three crankthrows, and, later, with the third and fourth cylinders at right angles to the first two, and in a vertical plane, giving the engine the form of a cross. This latter arrangement proved unsatisfactory, since, due to the imperfect splash lubrication systems then in use, the inverted cylinder flooded badly.

By removing this fourth, or inverted cylinder, and raising the horizontal ones slightly, the fan-type three-cylinder engine was obtained. The Anzani, see Fig. 56, was an example of this type. Here, the two side cylinders make angles of 72 degrees each with the vertical middle cylinder, which raises them slightly from their former horizontal position, as explained above. The great disadvantage of this type was in the uneven firing order, which gave unsteady running conditions and necessitated the use of a flywheel to smooth out the torque transmitted to the propeller. The firing order, referring to Fig. 56, was A, C, B, giving the following crank angle between power impulses: 144 degrees, 288 degrees, etc. This necessitated the use of a magneto driven at $1\frac{1}{4}$ times crankshaft speed, giving five sparks in two revolutions of the crankshaft. The

sparks occurred at equal intervals of 144 degrees, the third and fifth being wasted.

To increase running steadiness the vertical cylinder was inverted, a procedure made possible by the development of the pressure lubricating

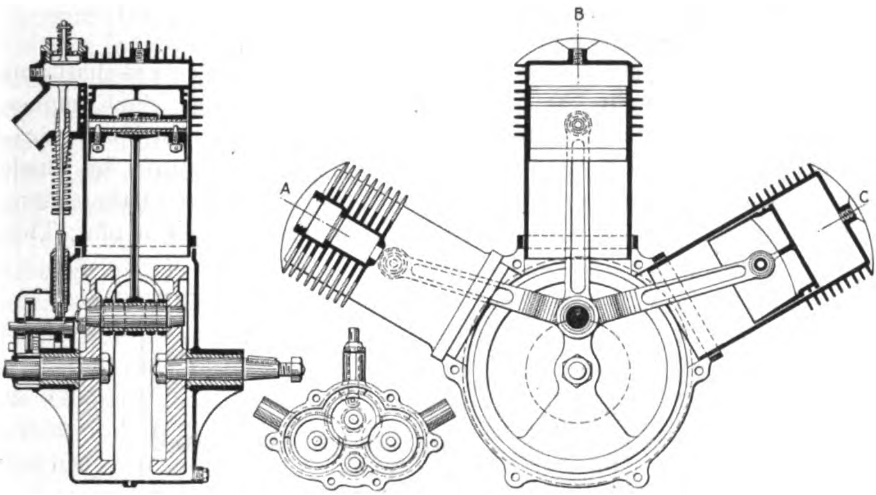

FIG. 54.—Anzani three-cylinder fan-type engine.

system, and the cylinders equally spaced in a Y-form, with 120 degrees between each two. This arrangement overcame the difficulties experienced in the fan type, and permitted the addition of intermediate cylinders, forming the radial engine. The number of cylinders in one plane

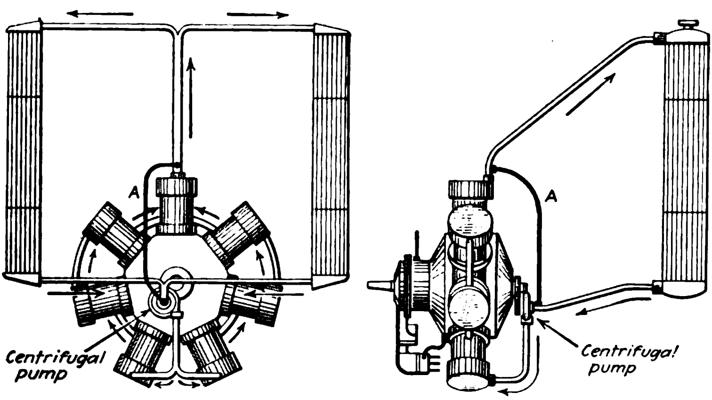

FIG. 55.—Water-cooling system of Salmson engine.

is limited only by space considerations, eleven being the maximum tried, but double this number was obtained by using two banks on two crank-throws, the cylinders in the rear bank being alternate with those in the front to facilitate cooling.

Most of these engines depended upon air cooling, the one important exception being the water-cooled Salmson, shown in Fig. 55. This unique arrangement of cooling system has proved satisfactory.

The large bore 9- and 18-cylinder models of this engine are horizontal types, as shown in Fig. 54. They are used exclusively for dirigible work, the propeller being bevel-driven.

The next development was the radial engine with fixed crankshaft and rotating case and cylinders, as the Gnome and LeRhone. Such engines must, of necessity, be air-cooled, and castor oil is always used as a lubricant, because of its superior adhesiveness at high temperatures, by which it maintains a film on bearings and cylinder walls in spite of the centrifugal force due to cylinder rotation, which tends to throw it off. This

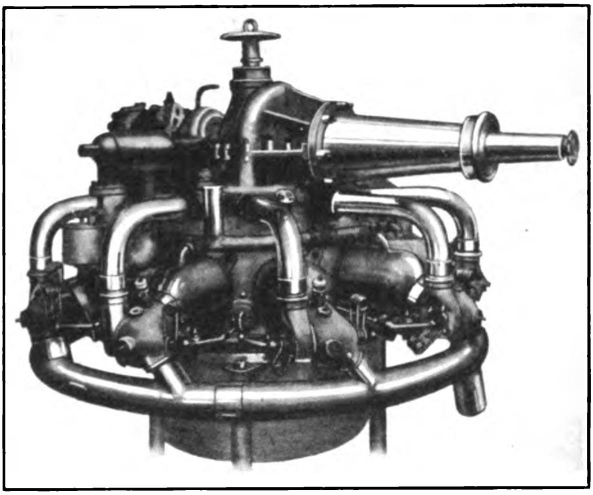

Fig. 56.—Horizontal Salmson engine.

type of engine is very light per horsepower, gives very even running torque, and is particularly adapted to stunt flying. It has been used successfully on airplanes for short flights, but its high rate of fuel consumption renders its use impracticable for long ones. Among the disadvantages are, a higher head resistance than any other type of engine, and the gyroscopic effect of the revolving cylinders.

By elimination of the vertical cylinder and longitudinal multiplication of the inclined cylinders on added crankthrows, the V-engine was developed. This type has become the favorite in this country, where it has been developed to the exclusion of the others.

55. Selection of Metal vs. Duty Performed. The study of the weight of the various typical engine parts gives information not only regarding weights, but also on reliability and adaptability. In making such a

study, it is necessary to consider all the functions of the part, and the characteristics of the material to be used.

The first requirement is resistance to stress, whether it be tension, torsion, bending or compression. Some members are subjected to different stresses alternately, or to several stresses at the same time. If a part is to be subjected to tension, combined or alternate with other stresses, it is best to select a material with high tensile strength. Steel is the metal generally used to meet these requirements, the preference being given to heat-treated alloy steel because it combines great strength with light weight. On the other hand, if the part is to be subjected only to short-column compression, or to crushing, almost any metal will serve. Cast iron or aluminum is generally used for this purpose, although neither offers high resistance to stress. For example, the cylinder is subjected to more than one stress at a time, as it is under tension during the power stroke of the engine and also must resist bending due to piston side thrust. In engines of the rotating-cylinder type, like the Gnome, the above stresses are increased because of the rotative action, and, in order to obtain minimum weight with required strength, steel has been substituted for cast iron or aluminum, as a cylinder material.

The principal stress on the piston is compression, and so cast iron or aluminum may be used in its construction. The piston pin, connecting rod and crankshaft are all subjected to heavy stress and are invariably made of steel. Some members, such as cams, are subjected to rubbing action resulting in great wear, and this necessitates the use of hardened steel for these parts.

The upper half of the crankcase is a heavily stressed member. It must resist the bearing stresses, stresses caused by explosion, and thrust. The lower half is not subjected to these stresses to any great extent and may be more lightly constructed.

It rarely happens that an engine part has only one function such as resisting stresses as this is usually accompanied by the additional function of transmission of heat.

In general when considering lubrication, the material of the rubbing parts must be considered. For example, the crankshaft is heavily stressed and for this reason must be made of steel. All bearing surfaces of the shaft are subjected to great wear and must be protected against destruction. The metal for the bearings must be selected from the viewpoint of lubrication and frequency of replacement. There are two types of bearings in general use; hard bearings usually made of brass, and soft bearings usually made of white metal. Where the bearings are accessible for inspection and where frequent adjustments are unnecessary, brass bearings are usually satisfactory. Where the bearings are not easily accessible for care and adjustments a soft bearing metal must be be used for if a brass bearing expands and seizes, it being harder than

babbitt, the shaft may be ruined. The best form of bearing for a crankshaft is a friction surface of babbitt with a brass back.

In gas engine construction it has been the accepted practice to use a cast iron piston in a cast iron cylinder. In other words, cast iron on cast iron was the only satisfactory combination from the standpoint of lubrication. This practice, however, has been discarded in aircraft engines, as aluminum pistons in steel cylinders are productive of satisfactory results at piston speeds considered impracticable in former gas engine practice.

As stated in the section on heat control, every engine part must be designed with the thought of heat transfer in mind. It is sufficient to state that if enough metal is provided to satisfy heat conditions, the part will be strong enough to meet the mechanical requirements.

Another function to be considered is the expansion of the materials under the application of heat. This has a large influence on clearances and adjustments, and also may cause undue stress in some engine parts. All parts must be adjusted when cold, with specified clearances in order to obtain desired conditions when the engine is running under operating temperatures and load. If the expansion of the cylinder and of the piston were equal, the working fit would be the same as when the engine is cold. The expansions, however, are not equal and clearances must be allowed which are the results of experiments. These clearances are suited only to the particular materials and conditions for which they are designed, and should the dimensions or material of any part, or the speed of the engine, or other operating condition be changed, the clearances must be altered to meet the new conditions. The rise in the temperature of the parts and the coefficient of expansion of the materials are involved in establishing clearances. Any two parts running in contact must have either the same coefficient of expansion, or they must be allowed sufficient clearance when cold to compensate for this difference. The effect of difference in temperature between two rubbing parts may sometimes be controlled or counteracted by the use of metals having different coefficients of expansion.

Up to this point, the typical construction of the aircraft engine has been discussed with reference to the arrangement of parts and the material used. The typical construction will now be considered with reference to the form of parts.

56. Aircraft Engine Cylinder Design and Construction. Aircraft engine cylinders were first made of cast iron, in the L- or T-head type, with iron jackets cast integral as in automobile practice as shown in *A* and *B* in Fig. 57. Due to the weight of the integral jackets, both these cylinder types were extremely heavy. The T-head engine also had the additional weight of the valve-operating mechanisms on both sides.

The logical improvement was to put the valves in the head rather than in an off-set pocket, and then to replace the cast jacket with a lighter form. Naturally, a cast iron jacket cannot be made very thin because a slight shifting of the core will spoil the casting. The most satisfactory jacket is formed of sheet metal and welded to the cylinder. The most desirable cylinder for aircraft engine is made of steel, and it was the common practice in the earlier days of aircraft engine construction to machine these cylinders from a solid steel billet. The method now in use is to use steel tubing or steel forging with a cylinder head welded in place, and to weld a sheet metal water jacket to the cylinder. The Hispano-Suiza engine is unusual in its cylinder construction. The cylinder walls and jackets are cast of aluminum, four enbloc. Steel cylinder sleeves, threaded for almost their entire length, are screwed into the aluminum jacket casting to provide the friction surfaces for the pistons, and also, to form the heat-resisting combustion chambers.

With a cast cylinder and jacket, a large water space must be allowed to guard against irregularity in metal thickness and to simplify moulding procedure. With a sheet-metal welded jacket, the water space can be cut down, reducing the weight of the water and increasing the speed of its flow. Ribs or flanges on the cylinder produce a more uniform cooling effect by diverting the flow of water around the cylinder. They also give it added strength.

57. Head Design and Valve Location. In considering cylinder and valve construction attention must be given to the design of the cylinder head and combustion chamber and to the location, size, and lift of the valves.

Illustration *A*, *B*, and *C* in Fig. 57 show vertical valve stems which are the most satisfactory because it has been proved by experiment that valves, placed in a horizontal or inclined position, wear in their guides. They are, therefore, difficult to keep tight on their seats as the valves hit on the lower sides first and tend to wear the valve seat in an elliptical shape. None but vertical valves are tolerated in large engines.

A poppet valve is wide open when its lift is ¼ the valve diameter. At high engine speed the inertia of the closing valve, with the action of the valve springs, develops a strong hammer blow both on the valve seat and on the valve gear. The intensity of this blow increases in proportion to the valve lift and the valve weight, so that it is desirable to reduce the lift and at the same time increase the valve diameter to maintain sufficient valve area. The arrangement shown at *C*, in Fig. 57, will not allow the valves to be increased sufficiently in diameter to provide the necessary valve area as the valve diameter is limited to half the cylinder diameter. This led to the development of the dome-shaped cylinder head, as used on the Austro-Daimler as shown in cylinder *D*, Fig. 57. Duesenberg introduced an engine with the valves arranged horizontally, but

it is so constructed that large valves can be used because of the enlarged combustion chamber, and the fact that very little resistance is offered to the flow of gases as shown by cylinder *E* in Fig. 57. A modification of the T-head cylinder, as shown at *B*, Fig. 57, can be seen at *F* in the same figure, but here the flare is continuous around the whole circumference and the valves seat in the flat cylinder head. Such an arrangement is used on the Curtiss V2. A combination of this type with the Austro-Daimler, is shown at *G*, Fig. 57, and is the form used on

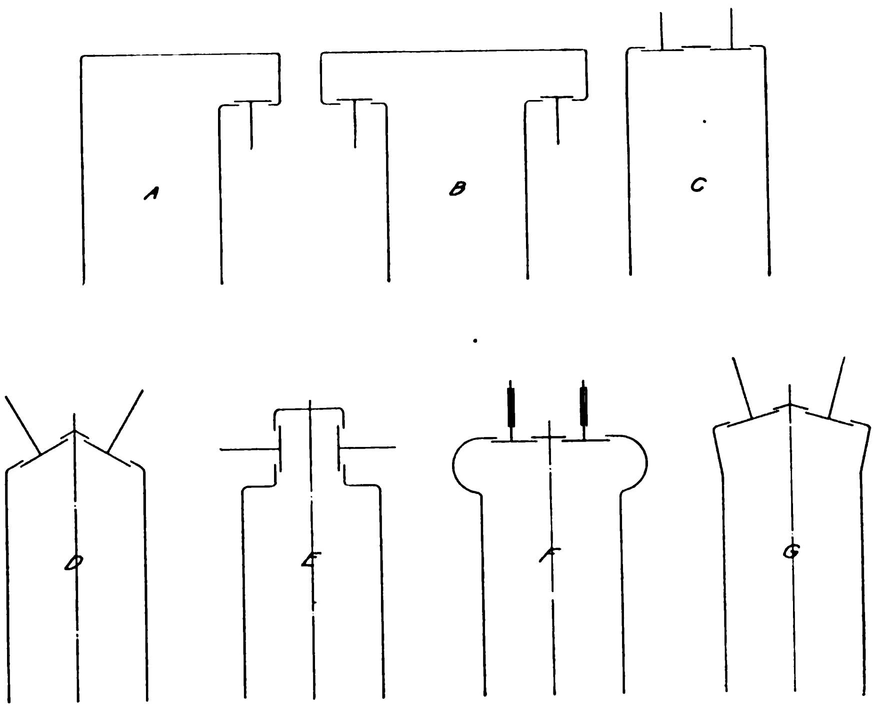

Fig. 57.—Aircraft engine cylinder development.

the Liberty. It approaches more nearly the ideal spherical shape and offers very little resistance to the flow of gases.

In connection with the study of cylinders the effects of offsetting cylinders in a gasoline engine should be considered briefly. By an offset cylinder is meant one in which the centerline does not pass through the center of the main bearings. The horizontal distance between the line of the main bearings and the centerline of the cylinders is called the "offset." See Fig. 58.

One of the advantages claimed for offset cylinders is a slight increase in length of the power stroke expressed angularly since the crank travels through more than 180 degrees between top and bottom center Another

advantage of this arrangement is that the piston does not accelerate as rapidly on the downward stroke, thus allowing combustion to take place under more nearly constant volume conditions. The increase in power resulting from the advantages claimed is so slight that t is hardly worthy of consideration. The advantage of offsetting seems a little more apparent when the decrease in side thrust is considered. With the average offset ratio, the power increase, due to this reduction is between 1 and 2 per cent. of the total power of the engine. The best results are obtained when the offset is approximately one-fourth of the cylinder diameter. In the Liberty engine, this would mean an increase of from 4 to 8 hp., and it is evident that such a small power increase would not be sufficient to warrant a change in construction. In view of the various difficulties involved very little use is made of the offset construction in present day aircraft engines, though it is in use in automobile practice. Offset cylinders are rarely found in V-type engines, though they appear in the Panhard, but the arrangement is used to some extent in the German, Austrian and Belgian cylinder-in-line types. The Anzani is an example of the application of cylinder offsetting to radial cylinder arrangement. The offset is obtained by tilting the cylinders slightly, either to one side or to the other, depending upon the direction of rotation, so that the centerline of the cylinders are off-center. Fig. 59 illustrates this construction.

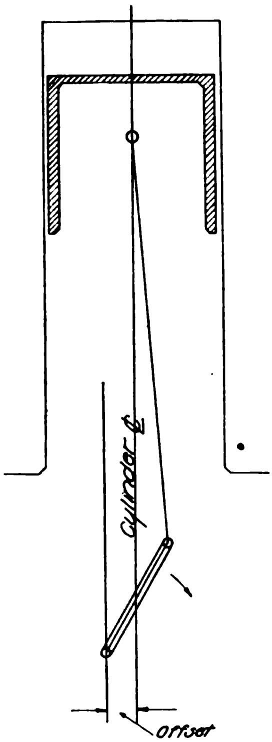

FIG. 58.—Offset cylinder.

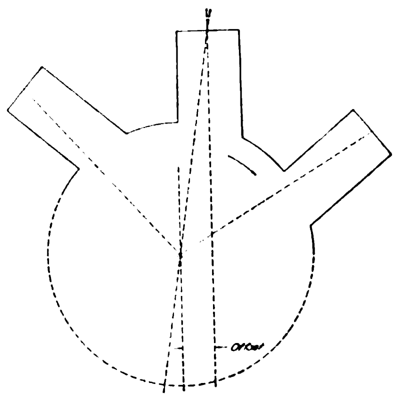

FIG. 59.—Offset cylinders in radial fixed-cylinder engine.

This principle is not employed in the rotating-cylinder types, but there is no apparent reason from the standpoint of construction, why it could not be used in the fixed radial.

Many types of valve gear are used with the valve-in-head type of cylinders. Some types have a rocker arm for each valve, operated by a push rod, which in turn is operated by the camshaft located in the crank-case. In V-type engines, a single camshaft located in the center ot the crankcase, may be used to operate the valves for both banks of cylinders. The lightest construction of this type of valve mechanism is that used in the Curtis OX engine. Here, a single camshaft is used and for each cylinder, one rod operates the rocker arm which actuates both exhaust and inlet valve. This rod is operated from a cam having both positive and negative lobes, thus making the rod both a pull, and a push rod. The overhead type of camshaft construction has many features in its favor, being lighter and more efficient. Although the weight of a second camshaft is added in the V-type engine the weight of the push rods is eliminated and the valve gearing simplified, making the action more positive due to the cams acting directly on the rocker arms which, in turn, actuate the valves. Overhead camshaft construction is more adaptable to engines having cylinders cast enbloc, for in this case a good substantial support is secured. With separate cylinders, difficulties are experienced because the cylinders do not stay in line, but *weave* and construction tending to tie the cylinders together is subject to great stress. On the Liberty engine the camshaft is placed in a housing and this housing takes most of the strain. Manifolds and water pipes also help to provide rigidity on the Liberty engine cylinder arrangement. This is open to criticism, however, as the tendency of such provision is to cause leaks.

It was previously stated that steel was the lightest metal from the standpoint of strength, so that separate cylinders could be made much lighter of steel than of cast iron. Cylinders cast enbloc, however, are lighter than cylinders cast separately, as there is a saving of metal between each two cylinders when cast, but they are heavier than forged, or machined steel cylinders.

Tappet clearances are very important, as incorrect clearances effect the valve timing. Therefore the nearer the camshaft is placed to the valves, the less possibility there will be for lost motion, and the more positive the valve action. Most overhead camshafts operate rocker arms that actuate the valves directly. These rocker arms have bearings in the camshaft housing and each bearing forming the fulcrum for its arm, while the one end of the rocker is in contact with the cam surface and the other end on the valve stem. This arrangement is used in the Hall-Scott and Liberty engines.

Some overhead camshaft types do not use rocker arms, but the cams bear directly on the valve stem or on a disk attached to it. This type is used on the Hispano-Suiza engine as shown in Fig. 60.

In this type, the valve stems are hollow and threaded inside to receive

the threaded sleeve attached to the disk on which the cam acts. Clearances are adjusted by turning the disk which may be locked in any position. This affords a very convenient method of adjusting tappet clearances. One objection to this construction is rapid wear, caused by the side thrust of the valve stem in its guide, due to the cam action on

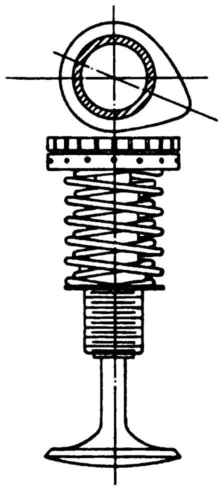

FIG. 60.—Cam action directly on valve stem.

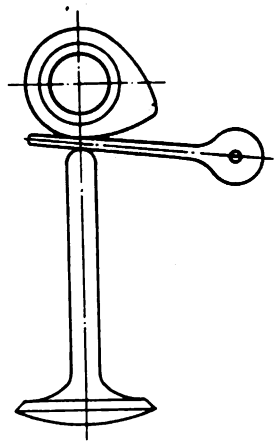

FIG. 61.—Cam action indirectly on valve stem.

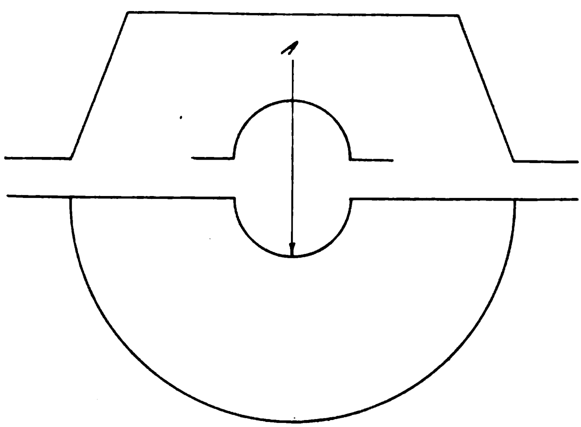

FIG. 62.—Bearing caps on lower half of crankcase.

the disk. The Sunbeam construction partially eliminates this objection by using a lever, the end of which bears on the valve stem, while the cam bears on the lever.

58. Crankcase.—Early in the development of aircraft engines, automobile practice was followed in crankcase design. This is shown in Fig.

62. Here the large load *a* acts on the main bearings and the strain is transmitted to the frame, in this case the lower half of the crankcase.

The next step in design, in both aircraft and automobile engine

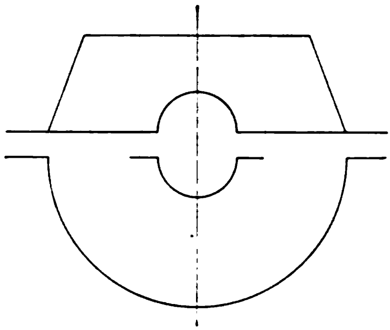

Fig. 63.—Bearing caps on upper half of crankcase.

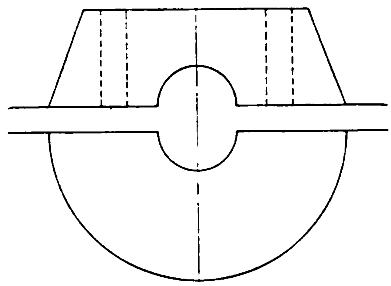

Fig. 64.—Bearings in both upper and lower halves of crankcase.

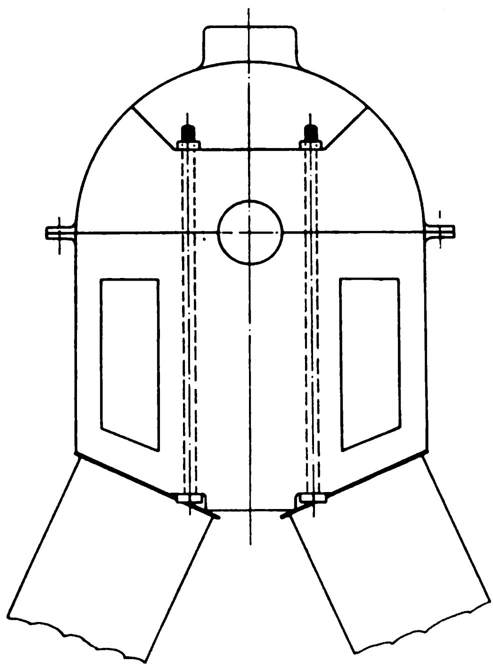

Fig. 65.—Liberty engine crankcase.

practice, was to make the upper half of the crankcase serve as the engine frame.

In this design the bearings are on top and the caps bolted on the bottom, as shown in Fig. 63, so that but little strain is carried by the lower half of the crankcase. It really serves merely as a cover and may be made very light, pressed steel frequently being used in its construction.

Fig. 65 illustrates another form of crankcase in which no bearing caps are used, the upper and lower sections of the crankcase each furnishing half of the main bearing supports. This construction, as illustrated in Fig. 66, is used in the Liberty engine.

The following table is presented to show a comparison of various aircraft engines from a viewpoint of power vs. piston displacement, and also weight vs. piston displacement.

TABLE IV.—COMPARISON OF TYPICAL AIRCRAFT ENGINES

Engine	B.hp.	Displ. in cu. ft.	Wt. dry	Wt. /per cu. ft. displ.	B.hp. per cu. ft. displ.	Lb. per B.hp.
Gnome	100	0.452	280	619	222	2.80
Curtis OXX	100	0.329	423	1290	304	4.23
Hall-Scott 7A	100	0.350	405	1160	286	4.05
Hispano-Suiza A	150	0.415	445	1090	362	2.93
Mercedes	160	0.522	618	1180	307	3.86
Curtis V2	200	0.636	690	1080	314	3.45
Hall-Scott L-6A	200	0.478	495	1035	419	2.48
Liberty (Navy)	385	0.956	820	857	403	2.13

Maintenance

59. Suggestions for Organization. For maintenance of aircraft engines, a definite plan of organization and routine is essential.

60. Inspection. Periodic inspection, both direct and indirect, should be made of every engine at stated times, either at the completion of a number of hours of engine operation, or at the expiration of a certain number of days. Direct inspection includes everything which can be seen and on which data can be recorded, together with dates. Forms should be provided, for this purpose. Indirect inspection involves the theory as to the causes of trouble. These theories and explanations form a valuable part of the log which would not appear in the recorded data. They are particularly valuable in drawing conclusions, and are of great assistance in recommending engine development.

61. Records. Time of engine operation should be recorded for each of the following:

Time when minor adjustments are necessary.
Time when minor replacements are necessary.
Time when major adjustments are necessary.
Time when major replacements are necessary.
Time when minor repairs are necessary.
Time when major repairs are necessary.

CHAPTER III

THEORY OF AIRCRAFT ENGINE PERFORMANCE

Introduction

62. Preliminary Talk. This subject is important because it treats of the various fundamental laws of physics, chemistry and mechanics that make possible the operation of internal combustion engines. Many statements, previously made during the course, are considered in more detail, and the student is prepared in the fundamentals of subjects which will be treated later.

Mechanics

63. Definition. *Mechanics is the science which treats of the forces acting on bodies.* It is divided into two classes depending upon whether the bodies are stationary or in motion.

64. Statistics. *Statistics is the mechanics of bodies at rest, or without motion.* It is the study of the forces acting in, or on, a stationary body. For example, the design of a bridge presents the problems of resistance to such stresses as tension, compression, bending and shear. There is no resultant motion here.

65. Dynamics. *Dynamics is the mechanics of bodies in motion, or the study of the forces which produce motion.* In an internal combustion engine the gases burn in the cylinder and exert a force on the piston. This force is transmitted through the connecting rod to the crank pin, producing rotation of the crankshaft. Therefore the study of these forces involves a problem in dynamics, since motion is produced.

66. Work. *Work is the expenditure of energy to overcome resistance.* It is customary to consider work as the product of force and distance. The unit of work is the foot-pound and is defined as the energy required to lift a weight of one pound through a distance of one foot. Thus, if a 15 lb. body is lifted 10 ft. against gravity, the work done is the product of the force times the distance, or 150 ft.-lb. If this same body is pulled along a table for a distance of 10 ft., the same amount of work will *not* be done because the force is not 15 lb. as before, but is the frictional resistance to motion. If a body, which requires a force of 15 lb. to move it, is pulled along a table a distance of 10 ft., the work done is the product of the force times the distance which, in this case, is 15 × 10, or 150 ft.-lb. The force acting is the pull, or actual force necessary to move the body.

Formula:

1. Work = Force times Distance.
2. Work = Pressure times Area times Distance.
3. Work = Pressure times Volume.

As previously shown, work equals force times distance and this is expressed by formula 1, above. Where a gas under pressure produces work, the total force is the product of the pressure per square inch, times the total area upon which this pressure acts. Thus, the term *force* may be divided into two factors, pressure and area. By substituting in place of force, its equivalent, pressure times area, the formula now becomes pressure times area times distance, as is represented by formula 2. Since volume is the product of area and distance, by substituting these in formula 2, the result is formula 3, or an expression of work in terms of pressure and volume.

The following are the usual methods of expressing the above relations, with the corresponding notation most commonly used.

$$1.\ W = FD$$

where, W = Work in foot-pounds.
F = Force in pounds.
D = Distance in feet.

$$2.\ W = PAD$$

where, W = Work in foot-pounds.
P = Pressure in pounds per square inch.
A = Piston area in square inches.
D = Distance in feet.

$$3.\ W = PV$$

where, W = Work in foot-pounds.
P = Pressure in pounds per square foot.
V = Volume in cubic feet.

Examples

1. To determine the work done by lifting a load of 116.5 lb. a distance of 10 ft.

$W = FD.$	W = Work in foot pounds.
$= 116.5 \times 10.$	F = 116.5 lb.
= 1,165 ft.-lb.	D = 10 ft.

2. To determine the work done during one stroke of a single piston in the Liberty engine, if the piston area is 20 sq. in., stroke 7 inches and mean effective pressure 100 lb. per sq. in.

$$W = PAD.$$
$$= 100 \times 20 \times .583.$$
$$= 1{,}166 \text{ ft.-lb.}$$

W = Work in foot-pounds.
P = 100 lb.
A = 20 sq. in.
D = 7 in. = $\frac{7}{12}$ or .583 ft.

3. To determine the work done per stroke by a single piston in the Liberty engine, if the piston displacement per cylinder is 140 cu. in. and the mean effective pressure is 100 lb. per sq. in.

$$W = PV.$$
$$= 14{,}400 \times .081.$$
$$= 1{,}166 \text{ ft.-lb.}$$

W = Work in foot-pounds.
$P = 100 \times 144 = 14{,}400$ lb. per sq. ft.
$V = \frac{140}{1{,}728} = .081$ cu. ft.

Note that the numerical results of the above examples are identical, but in each case a different method was used for computing the work done.

67. Torque. *Torque is the twisting effort, or the tendency to cause rotation.* The usual unit is the pound-foot but it may be expressed in other terms. It is the product of a lever arm which is measured in feet, and a force measured in pounds. It should not be confused with work. Torque is expressed in pound-feet to distinguish it from work, which is expressed in foot-pounds. Work cannot be produced without motion, but a torque can be exerted either with or without motion.

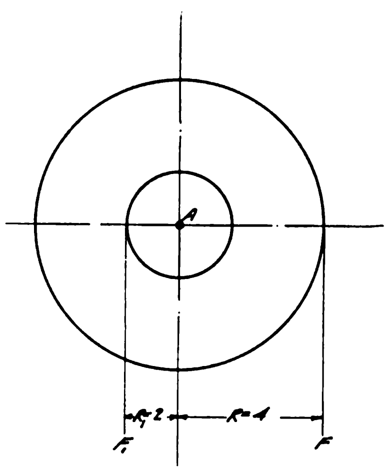

FIG. 66.—Torque.

As previously stated, torque is the ability to cause rotation. It is the product of a force and a lever arm, the lever arm measured perpendicular to the line of action of the force. In Fig. 67, two wheels are keyed to the shaft A, one wheel 8 ft. in diameter and the other 4 ft. in diameter. First, assume the shaft to be held stationary and a rope wrapped about the outer wheel. Attached to the rope is a weight of 100 lb. Thus, the force, $F = 100$ lb. and radius, $R = 4$ ft. Although no motion is produced, the wheel will tend to rotate in a clockwise direction and set up a torque, or twisting effort. The formula represents this effort as T. Then $T = FR = 100 \times 4 = 400$ lb.-ft. torque. This is an example of torque without motion.

Now assume that the shaft is rotating in a counter-clockwise direction and lifting the 100 lb. weight which is attached to a rope wrapped around the large pulley. A torque equal to FR pound-feet is exerted in a clockwise direction, rotation counter-clockwise, and is equivalent to

100×4, or 400 lb.-ft. The first example explained torque without motion and the second, torque with motion.

If the shaft is free to rotate and has a rope wrapped around the large pulley with a weight of 100 lb. attached, as in Fig. 67, it will rotate in a clockwise direction. Now let a rope be wrapped around the small pulley whose radius is one-half that of the large one. It is necessary to

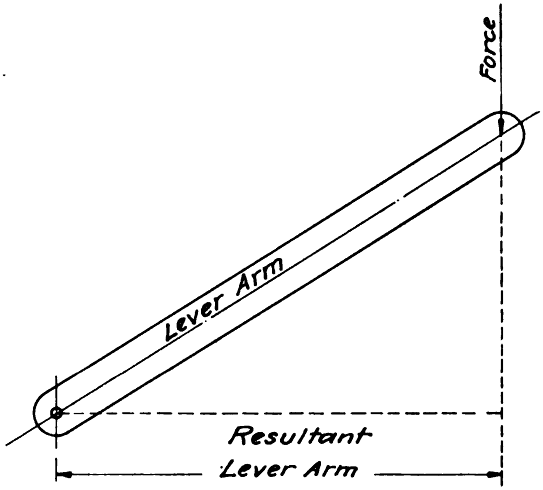

FIG. 67.—Resultant lever arm.

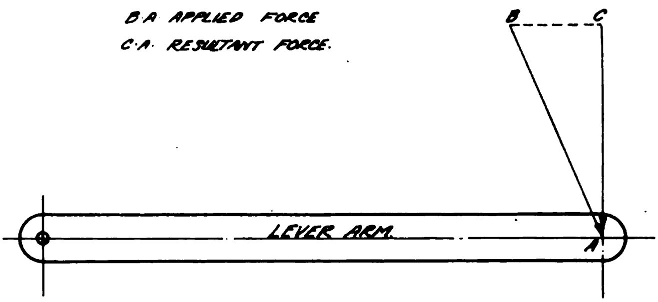

FIG. 68.—Resultant force.

suspend a weight of 200 lb. in order to prevent rotation. This is T_1, or clockwise torque, and equals T_2, the counter-clockwise torque. This can be expressed as:

$$T_1 = T_2$$
$$\text{But, } T_1 = FR$$
$$\text{And } T_2 = F_1R_1$$
$$\text{Therefore, } FR = F_1R_1$$

It is evident, therefore, that if F is decreased, R must be increased in the same ratio, to obtain the same torque.

It is absolutely essential that the lever arm be measured at right angles or the direction of application of the force. If the two do not act at right angles, it is necessary to find the resultant lever arm as in Fig. 67, or the resultant force as in Fig. 68.

Example. What torque will be exerted by a single cylinder of the Liberty engine, when the crank and the connecting rod makes an angle of 90 degrees; if the force on the crank pin is 2,000 lb. and the crank throw 3½ in.?

$$\begin{aligned} T &= FR. \\ &= 2{,}000 \times .29. \\ &= 582 \text{ lb.-ft.} \end{aligned} \qquad \begin{aligned} T &= \text{Torque in pound-feet.} \\ F &= 2{,}000 \text{ lb.} \\ R &= 3\tfrac{1}{2} \text{ in.} = \frac{3.5}{12} = .29 \text{ ft.} \end{aligned}$$

68. Power. *Power is the rate of doing work.* In other words, the element of time necessary to accomplish the work is considered. Power is obtained by dividing work by time, and is a specific amount of work per unit time, as; 200 ft.-lb. per sec., 2,000 ft.-lb. per hr. The distinction between work and power should be clearly understood. Work is the *quantity* of energy expended but power is the *rate* of expending energy, or the rate of doing work. Two machines may each develop 1,000 ft.-lb. of work, but if one does this work in one minute, and the other requires two minutes, the first machine develops just double the power of the second, because its rate of doing work is twice as great. If a man climbs from the ground to the top of a building in two minutes, and again in four minutes, he does the same amount of work each time. But when going up in two minutes he develops double the power because the rate of doing the work is doubled.

The mechanical unit of power is the *horsepower.* 33,000 ft.-lb. of work per minute is equivalent to one horsepower. If 66,000 ft.-lb. of work is produced per minute, then $\frac{66{,}000}{33{,}000}$ or 2 hp. is developed. It is evident, therefore, that the horsepower developed is obtained by dividing the foot-pounds of work per minute by 33,000.

$$\text{Horsepower} = \frac{\text{Work per minute (foot-pounds)}}{33{,}000}$$

Indicated-horsepower is the power actually developed in the engine cylinder by the burning gases. It is usually determined by calculation based on indicator cards taken from the engine cylinders during operation. The mean effective pressure is determined from the indicator card and this value, together with known values from the engine, are substituted in the following formula:

$$\text{I.hp.} = \frac{PLAN}{33{,}000}$$

It has been stated that work is the product of force times distance. The work per stroke of the engine is then $PA \times L$, and work per minute is $PA \times L \times N$ where N is the number of power strokes per minute. Therefore,

$$\text{I.hp.} = \frac{(PA)LN}{33{,}000}, \text{ or } \frac{PLAN}{33{,}000}.$$

The correct meaning of the term N must be emphasized. It is the number of power strokes, or explosion strokes, per minute for the cylinder under consideration. On a four-cycle engine of the aircraft type, N is equal to half the revolutions per minute, while for a two-cycle engine N equals the r.p.m. On stationary engines where the hit-and-miss type of governor is used, the number of explosions per minute must be counted. The horsepower determined by the above formula is for *one* cylinder only; and the total horsepower of the engine is the sum of the horsepower output of all of its cylinders.

Inasmuch as it is very difficult to obtain indicator-card diagrams from engines running at speeds over 600 r.p.m., it has become common practice to compare aircraft engines on a basis of brake mean effective pressure.

Example. To determine the brake mean effective pressure developed by a 4-cylinder Hall-Scott engine operating at 1,400 r.p.m., and developing 100 horsepower at the brake, piston area being 20 sq. in., and stroke 7 in.

$$\text{Hp.} = \frac{PLAN}{33{,}000}$$

$$\text{or, } P = \frac{33{,}000 \text{ hp.}}{LAN}$$

$$= \frac{33{,}000 \times 100}{.583 \times .20 \times 2{,}800}$$

$$= 101 \text{ lb. per sq. in.}$$

B.hp. = 100

P = brake m.e.p. in lb. per sq. in.

L = 7 in. = .583 ft.

A = 20 sq. in.

$$N = \frac{\text{r.p.m.}}{2} \times \text{number of cylinders}$$

$$= \frac{1{,}400}{2} \times 4 = 2{,}800$$

Of the power made available in the engine cylinder (indicated horsepower) by the combustion of the fuel charge, only 75 to 85 per cent. is actually delivered to the flywheel or propeller. The other 15 to 25 per cent. is lost in overcoming friction of the bearings and working parts of the engine, in pumping losses, and in operation of auxiliaries. All power so employed is included in *friction horsepower*.

Under the head of *rubbing parts* are included all frictional losses due to the rubbing of one part over another, such as the main bearings,

connecting-rod bearings, piston-pin bearings, thrust bearings and camshaft bearings, plus the friction between the piston and cylinder wall. No net power loss is caused by operating the valve springs, because the power which they absorb during compression is released when they expand, but due to the pressure against the bearings, some friction is developed and considered as camshaft bearing friction.

About 70 to 80 per cent. of the frictional horsepower is due to rubbing parts, and of this, from 60 to 70 per cent. is used to overcome the piston friction due to side-thrust. The greater the side-thrust the greater the friction, and since a small rod-crank ratio increases the side-thrust, it is evident that a larger per cent. of the frictional horsepower will

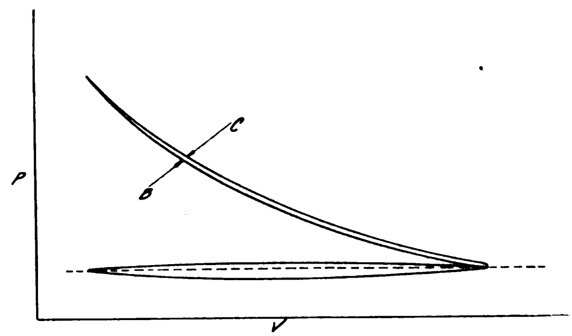

Fig. 69.—Indicator card.

be charged to the pistons when a small rod-crank ratio is used. Considerable power is used to draw in, and expel the gases from the cylinder, but with modern engines in which high volumetric efficiency is obtained by using large valves properly operated, this power loss is decreasing, and at present for aircraft engines, is about 10 to 30 per cent. of the total frictional horsepower. These pumping losses are represented by the lower loop, *B*, of the indicator diagram in Fig. 69.

It is usually assumed that no net work is done by compressing the gases in the cylinder, but actually some work is done, as shown by Fig. 69. This card shown in the figure was obtained by running the engine, by means of a motor, at normal speed without igniting the fuel charge. Line *c* represents compression, and line *b* represents expansion. The area between these two lines represents the actual work absorbed in compression. With high-speed engines, this may be 20 per cent. of the total pumping losses, although it is usually assumed that the pumping losses include those losses only due to the drawing in and expelling the gases. If true adiabatic compression and expansion could be obtained, no work would be lost. Adiabatic treatment of the mixture is impossible and some heat is sure to be lost, resulting in the drop in the expansion line, as shown in Fig. 69.

Operating the water pump, oil pump, ignition apparatus and other auxiliaries absorbs 10 or 15 per cent. of the total friction horsepower.

The following procedure is generally used to determine friction horsepower. An engine is mounted on a test stand, and connected to an electric dynamometer which will measure the power developed. When the dynamometer is used as the driver, it will measure the power necessary to rotate the engine. Suppose this same engine, when operating under its own power at 1,000 r.p.m., develops 600 b.hp. If in driving the engine at 1,000 r.p.m., with the electric motor, the power required is found to be 100 hp., it is evident that the total frictional horsepower of the engine at that speed is 100 f.hp. After removing the oil pump, ignition apparatus and all other auxiliaries, the power necessary to drive the engine at 1,000 r.p.m., is again noted. The difference between the total frictional horsepower and this reading represents the power necessary to operate the auxiliaries. With all valves and cylinder caps removed, so that no work will be done in drawing in and expelling the gases, the engine is driven at the same speed as before noting the required power. Subtracting this power reading from the one recorded when running without auxiliaries, the power loss due to pumping is found. The remainder of the power loss is assumed to be the power lost due to rubbing parts.

By summing up these various power readings they will approximate the following proportions:

	100%	= Indicated horsepower.
	15 to 25%	= Friction horsepower.
(*a*)	70% to 80% of F.Hp.	= Power lost to rubbing parts.
	60% to 70% of (*a*)	= Power lost to piston.
	30% to 40% of (*a*)	= Power lost to journals.
(*b*)	10% to 15% of F.Hp.	= Power lost to pumping.
	60% to 90% of (*b*)	= Power lost to drawing in and expelling gases.
	10% to 30% of (*b*)	= Power lost to compression.
(*c*)	10% to 15% of F.Hp.	= Power lost to auxiliaries.
	75% to 85% of I.Hp.	= Brake horsepower.

The difference between the indicated horsepower and the friction horsepower, or the power available to do useful work, is known as the brake-horsepower. It received its name from the fact that it was originally measured by a Prony brake.

Fig. 70, illustrates a form of the Prony brake used for measuring horsepower. It consists of a set of blocks which can be applied to the rim of a flywheel, or pulley secured to the flywheel or crankshaft, with adjustable pressure. The friction between the blocks and pulley will absorb the power output of the engine and convert it into heat. The blocks are

secured to an arm whose outer end rests upon the platform of a beam scale, or is attached to a spring scale. Referring to Fig. 70, when the engine rotates in the direction indicated by the arrow, it will cause the scale to indicate a pressure. This pressure is due partly to the friction of the blocks on the drum, and partly to the weight of the arm. Since it is desired to determine the friction alone, either a correction must be made for the weight of the arm resting on the scale, or the effect must be eliminated by providing a counterweight on the side opposite the arm, so that the brake will balance around the center of the bore of the brake blocks.

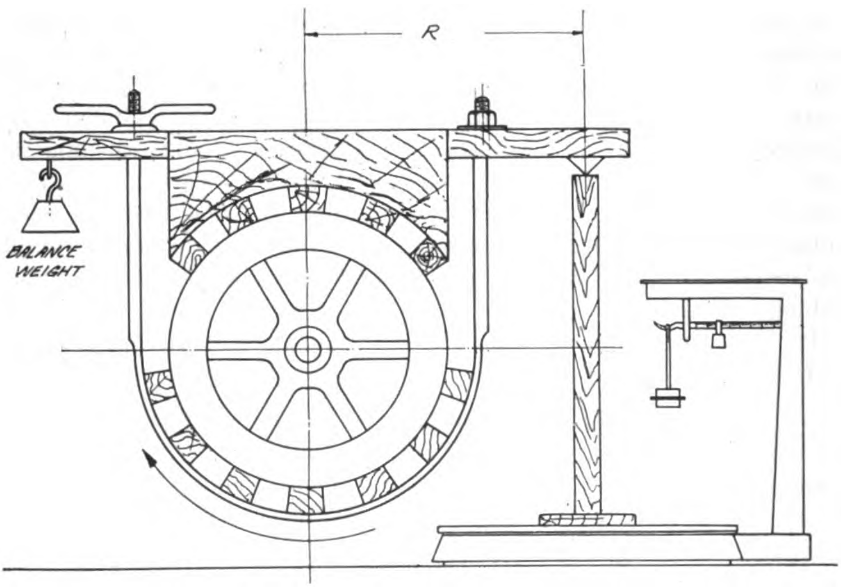

FIG. 70.—Prony brake.

The horsepower formula applicable to the Prony brake is derived as as follows:

$$\text{Hp.} = \frac{\text{Work per minute (foot-pounds)}}{33000}$$

If the brake arm were integral with the pulley and allowed to rotate, it would describe a circle with a radius of R, and a circumference of $2\pi R$. If it were possible to measure the force applied at the end of the arm, the work done per revolution would be $2\pi RF$, where F is the force applied. It would, therefore, be an easy matter to measure the power developed if the above assumptions were true. It is simpler to keep the brake arm stationary, measuring the load at its knife edge and allowing the wheel to slip inside of the friction blocks. As this arrange-

ment gives the desired results it is possible to consider the formula as follows:

$$W = 2\pi RF = \text{Work per revolution.}$$
$$N = \text{r.p.m.}$$

Therefore, $2\pi RFN = $ Work per minute in foot-pounds

when R is in feet, and F in pounds.

Therefore, $\dfrac{2\pi RFN}{33000} = $ Horsepower developed,

or, $$\text{b.hp.} = \frac{2\pi RFN}{33000}.$$

But $$\frac{2\pi}{33000} = .00019$$

Therefore, $$\text{b.hp.} = .00019\ RFN$$
$$\text{Torque} = T = FR$$

Therefore, $$\text{b.hp.} = .00019\ TN.$$

This is the brake horsepower formula reduced to its simplest terms and expressed, in the first case, in terms of brake arm, force and speed, and in the second case, in terms of torque and speed.

$$\text{B.hp.} = .00019\ RFN$$
$$= .00019\ TN$$

B.hp. = Brake horsepower.
F = Brake load in pounds.
R = Length of brake arm in feet.
N = r.p.m.

Example. A Liberty engine exerts a load of 220 lb. on a brake arm 5 ft. 3 in. in length, when rotating 1,700 r.p.m. Determine the b.hp. developed.

$$\text{B.hp.} = .00019\ RFN$$
$$= .00019 \times 220 \times 5.25 \times 1{,}700$$
$$= 372 \text{ b.hp.}$$

B.hp. = Brake horsepower.
R = 5 ft. 3 in. = 5.25 ft.
N = 1,700 r.p.m.
F = 220 lb.

69. Motion. *Velocity is the rate of motion, travel or speed.* It may be expressed in several units such as miles per hour, feet per second, or feet per minute. In this work it will be considered only as feet per second, or feet per minute.

Example. A crank with a throw of 6 in. is rotating at 1,000 r.p.m. What is the velocity of the crankpin in feet per second?

$$V = \frac{2\pi RN}{60}$$
$$= \frac{2\pi \times .5 \times 100}{60}$$
$$= 52.3 \text{ ft. per sec.}$$

V = Velocity in feet per second.
R = 6 in. = .5 ft.
N = 100 r.p.m.

Acceleration is the rate of change of velocity and is usually expressed in feet per second per second.

Example. A train travelling at the rate (velocity) of 10 miles per hr., increases is speed at a uniform rate until, in 20 sec. it is moving at the rate of 30 miles per hr. What is the acceleration?

Final velocity = 30 miles per hr.
Initial velocity = 10 miles per hr.
Change in velocity = 20 miles per hr.

That is, in 20 sec. the train changed its velocity 20 miles per hr., or its acceleration is 20 miles per hr. in 20 sec., which is equivalent to one mile per hr. in one sec., or, $\frac{5{,}280}{3{,}600} = 1.44$ ft. per sec. per sec.

The acceleration can be either positive or negative, depending upon whether the velocity is increased, or decreased. Negative acceleration is called *retardation.*

Physical Units

70. Density. *Density is the weight of a substance per unit volume.* It may be expressed as pounds per cubic foot, ounces per cubic inch, or in various other terms; the usual unit, however, is weight per cubic foot. Thus the density of water is 62.5 lb. per cu. ft., and the density of air is .0807 lb. per cu. ft.

To be accurate, the density must be limited by pressure and temperature, especially in the case of gases, because they expand and contract greatly. Gases are usually specified at 32° F. and 14.7 lb. per sq. in. pressure. There is no standard for liquids, but usually the density is specified at 14.7 lb. per sq. in. pressure and 60° F.

71. Specific Gravity. *Specific gravity is the ratio of the weight of a substance to the weight of an equal volume of water.* It might also be stated as the ratio of the density of the substance to the density of an equal volume of water, when measured at the same temperature and pressure, being expressed as follows:

$$\text{Specific gravity} = \frac{\text{Density of substance}}{\text{Density of equal volume of water}}.$$

If the substance is heavier than water its specific gravity will be greater than unity; if lighter than water its specific gravity will be less than unity.

Examples

(*a*) Ice weighs 50 lb. per cu. ft. What is its specific gravity?

$$\text{Specific gravity} = \frac{50}{62.5} = .8.$$

(*b*) Mercury weighs 849 lb. per cu. ft. What is its specific gravity?

$$\text{Specific gravity} = \frac{849}{62.5} = 13.6.$$

The *hydrometer* is an instrument for measuring the density of liquids. It is usually made of glass, being composed of three parts; a small bulb filled with shot, a tube filled with air, mounted just above the bulb, and a small stem in which the scale is inserted.

The hydrometer, or float as it is often called, is placed in the liquid and allowed to come to rest. The specific gravity is read on the tube at the surface of the liquid. Having the specific gravity reading, the density can be obtained from a table or computed from the formula.

The Baumé scale is often substituted for the specific gravity scale in the neck of the float. The former scale being an arbitrary one,

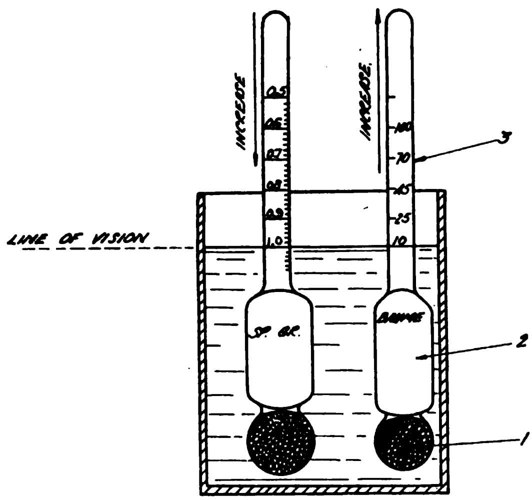

FIG. 71.—Hydrometer.

records degrees Baumé rather than actual specific gravity. The relative specific gravity can be obtained from a table or from the formula,

$$\text{Specific gravity} = \frac{140}{130 + \text{degrees Bé.}} \text{ for liquids}$$

lighter than water. For liquids heavier than water, a conversion formula is provided,

$$\text{Specific gravity} = \frac{145}{145 - \text{degrees Bé.}}.$$

Note the two floats in Fig. 71 and their relation. As the liquid decreases in density the floats will sink, giving a lower specific gravity reading and a higher Baumé reading. Therefore, a decrease in the density of the liquid means a decrease in the specific gravity and an increase in the Baumé reading.

As a rule the Baumé scale is used in recording the density of gasoline and oils, whereas the specific gravity scale is used in recording the density of the electrolyte of storage batteries.

Mechanics of Fluids

72. Pressure vs. Head of Fluids. A liquid may be considered as being composed of very small particles, between which the cohesion is so slight that the molecules may change their relative positions on the application of a very small force.

In the study of the relation between the pressure exerted by a liquid and the total head of liquid it must be emphasized that the pressure can be expressed in any unit. It usually is expressed in pounds per square inch. The head is the vertical distance from the point under consideration to the top of the liquid and is usually expressed in feet.

The usual method is to determine the pressure resulting from a one foot head of liquid. Knowing this valve the pressure exerted by any head can be determined by simple multiplication.

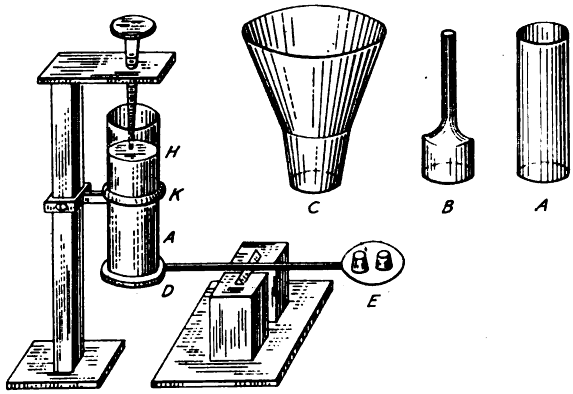

Fig. 72.—Graphical representation of fluid pressure.

One cubic foot of water weighes 62.5 lb. That is, the pressure exerted by a cubic foot of water on one square foot of surface would be equal to 62.5 lb. To determine the pressure in pounds per square inch 62.5 lb., the weight per cubic foot, must be divided by 144, the area in square inches of the base. The quotient is the pressure per square inch resulting from a one foot head. This value is equal to .434.

If it were possible to cut up a cubic foot of liquid, as shown in Fig. 72, into small columns one inch square and one foot in height there would be 144 such columns. Each column would exert a pressure in pounds per square inch equal to the total weight per cubic foot or the density of the liquid divided by 144. To determine the pressure exerted on one square inch by a one foot head of water divide 62.5 by 144 and a result of .434 lb. will be obtained.

Mercury weighs 849 lb. per cu. ft. Dividing this by 144, the pressure in pounds per square inch exerted by a one foot head would be equal to 5.9 lb.

At atmospheric temperature and pressure one cubic foot of air weighs .0807 lb. Therefore, the pressure in pounds per square inch due to a one foot head would be equal to .0807 divided by 144 or .00056 lb.

To find the pressure in pounds per square inch for a one foot head of any fluid, a simple formula may be used.

$P = HK$ where, K = constant for specific liquid or pressure in pounds per square inch due to a one foot head. This is equal to $\frac{D}{144}$ or the density divided by 144.

In Fig. 72, the constant K would be equal to the weight of the column of fluid shown at X.

73. Flow of Fluids. Theoretically speaking, steady, uniform flow of liquid never exists. There is a steady, uniform flow only, when all the molecules of the liquid have the same velocity and pressure when passing a definite point of the stream.

Eddy currents are always present in flowing liquids, the velocity of the flowing particles increasing with their distance from the surfaces bounding the stream. As an example of this, it is noticed that the velocity of the water near the bank of a river is always less than the velocity at the middle of the stream.

In calculating various problems, however, it is assumed that a steady uniform flow exists, that there is no friction between the particles in the liquid, and that the velocity of the particles is the same in any specific normal section of the flow.

In determining the weight, quantity, and velocity of flowing liquid it is necessary to modify the different formulas with certain coefficients, depending upon the size, shape and surface of the orifice through which the liquid flows. The average hydraulic coefficient is approximately .6.

The weight of liquid discharge depends directly upon the volume of liquid flowing in cubic feet per second and its density.

$W = QD$ where,

W = Total weight of liquid discharged in pounds.
Q = Volume of liquid discharge measured in cubic feet per second.
D = Density of liquid.

Determine the weight of water discharged in one hour, flowing at the rate of 0.5 cubic feet per second.

$W = QD = (.5 \times 60 \times 60) \times (62.5) = 112{,}500$ lb.

The quantity of liquid discharged depends directly upon the area

of the orifice and the velocity of flow. The area of the orifice is usually measured in square feet and the velocity in feet per second.

$Q = AV$ where,

Q = Cubic feet of liquid discharged per second.
A = Area of orifice in square feet.
V = Velocity in feet per second.

An orifice has an area of 14.4 sq. in. The liquid flows at the rate of 40 ft. per sec. Determine the quantity discharged in two minutes.

$$Q = AV = \left(\frac{14.4}{144}\right) \times (40) \times (2 \times 60) = 480 \text{ cu. ft.}$$

The velocity of flow is directly dependent upon the head of the liquid.

$V = \sqrt{2gh}$ where,

V = Velocity in feet per second.
g = Acceleration constant due to gravity (32.2 at sea level).
h = Head in feet above orifice.

For approximate calculation the above formula can be written as

$$V = \sqrt{2gh} = \sqrt{2 \times 32.2h} = \sqrt{64.4h} = 8\sqrt{h}$$

Determine the velocity of flow of water under a head of 200 ft.
$V = 8\sqrt{h} = 8 \times \sqrt{200} = 8 \times 14.15 = 113.2$ ft. per sec.

In all of the above formulas it is necessary to modify the results by the nozzle coefficient, depending upon the size, shape and surface of the orifice.

74. Viscosity of Fluids. *Viscosity* is the resistance the molecules offer when changing their position. It might be termed molecular friction, or the resistance that a liquid offers to change of shape. Relative measures are made of the viscosities of liquids by noting the time in seconds it takes for a definite amount to pass through a standard opening at a definite pressure and temperature. The cohesive qualities of a liquid should not be confused with the adhesive qualities. The cohesive power or quality of a liquid is the ability its molecules have to cling together. Adhesive power is the ability the molecules have to cling to the surfaces with which they come in contact.

When heat is applied to a liquid, the energy separates the molecules and subdivides them. As a result the molecules, in passing through an opening, will go faster and offer less resistance to flow. Therefore, the viscosity is lower. Where the opening is small and skin friction begins to interfere, the viscosity will vary as much as 100 per cent. This is noticable within the temperature limits at which a carburetor acts. The higher the temperature, the lower the viscosity, and *vice versa*, the lower the temperature the higher the viscosity.

Thermal Units

75. Heat Energy. Heat is a form of energy and it is responsible for changes in temperature. When two bodies of different temperature are placed in contact, the temperature of the warmer will fall, while that of the cooler will rise until both reach the same temperature. To account for this phenomena, it is said that heat "flows" from the warmer to the cooler body. The drop in temperature of the warmer body and the rise in temperature of the cooler body is due to this transmission of heat. The theory of heat is advanced to account for this temperature change, just as the theory of force is advanced to account for the observed motion of bodies. Whatever may be the nature of heat, it can be measured, and therefore it has quantity.

Heat may be generated by the expenditure of mechanical energy, as for example, the heating of journals due to friction, the heating of air, or gas, by compression. On the other hand, work may be performed by the expenditure of heat, as in the steam engine, the gasoline engine, and other heat engines. It has been proven by experiment that a definite relation exists between heat energy and mechanical energy. To produce a unit of heat a definite amount of work must be performed. Hence, it may be said, that heat energy and mechanical energy are equivalent and the relation between them is constant.

In addition to these forms of energy there is the chemical energy generated by an explosive, and electric energy as in an electric current. These forms of energy are more or less interchangeable, as, for example, a power station where the chemical energy in the coal is changed during the process of combustion, into heat energy in the steam. This form of energy in turn is transformed into mechanical energy in the engine or turbine which, if used in driving an electric generator, develops electrical energy.

In such a series of transformations it is often stated that a loss of energy occurs. This conception is incorrect for experience has proven that the total energy of an isolated system remains constant and cannot be increased or diminished by a physical process.

Therefore, any apparent loss of energy is due to the imperfection of the methods for transformation of energy. The heat energy generated on the grate is not all transferred to the water in the boiler, and the heat energy in the steam is not all transformed into mechanical energy in the engine. A certain amount of energy in either transformation, escapes in the exhaust. Similarly some of the mechanical energy of the engine is used in overcoming frictions, and is not available for transformation into electrical energy. This tendency to lose energy is due to the imperfections of machines only, and the total amount of energy being an isolated system is always constant.

The quantity of heat may be measured by noting the effects produced by its presence on certain substances. A certain amount of heat is necessary to raise a given amount of a substance through certain specified range of temperature. In this way the unit of heat is obtained, which is that amount of heat necessary to raise the temperature of one pound of water from 63° F. to 64° F. and is known as the British thermal unit.

76. Temperature. Temperature may be called the intensity of heat pressure in a given body. This will be clear if pressure is considered in the ordinary sense. As an example, a charge in an engine cylinder at the beginning of the compression stroke, the inlet valve having just closed. The gas in this case is under atmospheric pressure. The amount of charge at the end of the compression stroke or at the point of ignition is unchanged but the volume in which it is contained has decreased and the pressure is greater. If the charge is considered as an amount of heat, the volume of the cylinder at the beginning of the stroke as one body and the volume at the end of the stroke as a smaller body, the same amount of heat in the smaller body will be contained under a greater pressure than in the larger and this intensity of heat pressure thus registered, is known as temperature. A certain number of B.t.u.'s added to one pound of water will give a certain temperature; this same amount of heat added to one-half pound of water will give it a higher temperature. This theory of temperature also aids in understanding the flow of heat from a body of higher to one of lower temperature. Gas or water under pressure will flow to a container under a lower pressure until an equilibrium of pressures is reached. Heat contained in a body acts in a similar manner.

It is to be understood that a sharp distinction should be drawn between the terms heat and temperature.

There are many scales for measuring temperature, but there are only two in general use, the Fahrenheit and the Centigrade scales. The Fahrenheit is generally used in English-speaking countries, while the Centigrade is used in most European countries. The Centigrade is used in scientific work, to some extent, in this country.

Both scales are based upon two fundamental points, the temperature melting ice, and the temperature of boiling water, at sea level under atmospheric pressure. On the Fahrenheit scale this range is divided into 180 equal divisions each division being called a degree. In the Centigrade scale, there are only 100 equal divisions in the same range. Therefore 1 degree on the Fahrenheit scale equals $^{100}/_{180}$ or $^5/_9$ of a degree on the Centigrade scale. Conversely 1° C. = $^9/_5$ of a degree of Fahrenheit.

$$180° \text{ F.} = 180 \times {}^5/_9 = 100° \text{ C.}$$
$$100° \text{ C.} = 100 \times {}^9/_5 = 180° \text{ F.}$$

The zero of the Centigrade scale is at the point of melting ice. This point, however, is taken as 32 degrees on the Fahrenheit scale, and this variation must be provided for in changing a given temperature on one scale to the correct figure on the other. In changing from Centigrade to Fahrenheit add the 32 degrees to the converted reading

$$T_F = \tfrac{9}{5}(\text{C.}^\circ + 32^\circ)$$

By this formula 15° C. = $(\tfrac{9}{5} \times 15) + 32 = 27 + 32 = 59°$ F.

In changing from Fahrenheit to Centigrade, subtract the 32 degrees from the Fahrenheit reading, to make the two scales equal between the fundamental points and multiply the remainder by $\tfrac{5}{9}$.

$$T_C = \tfrac{5}{9}(\text{F.}^\circ - 32^\circ)$$

By this formula, 59° F. = $\tfrac{5}{9}$ (59 − 32) = $\tfrac{5}{9} \times 27$ = 15° C.

The boiling points in the two scales will then be 100° C., and 180° + 32° = 212° F. A comparison of the two scales is shown in the following table.

Table V.—Comparison of Temperature Scales

Fahrenheit	Centigrade	Comparative temperatures: Fahrenheit	Comparative temperatures: Centigrade
212	100	350	176.7
		300	148.9
		250	121.1
		212	100.0
	Boiling Point of Water		
		206	93.3
		100	37.8
		75	23.9
		50	10.0
	Melting Point of Ice		
59	15	32	0.0
		30	− 1.1
		20	− 6.7
		10	− 12.2
		0	− 17.8
	Absolute Zero		
32	0	− 459.6	− 273.1
0	17.8	F. = $\tfrac{9}{5}$(C.° + 32°)	C. = $\tfrac{5}{9}$(F.° − 32°)

So far an arbitrary zero has been taken for each scale; the point of melting ice on the Centigrade, and 32 degrees below this point on the Fahrenheit. The difference between two temperatures t_1 and t_2, or the expression $(t_1 - t_2)$ is always constant irrespective of the zero above which the temperatures are taken. Therefore any point may be taken as zero and the temperature indicated as T_1 and T_2. This expression becomes $(T_1 - T_2)$, but its value remains unchanged. It is a well-known fact that the pressure of a gas decreases as the temperature of that gas decreases and it is possible to imagine a point where the pressure will become zero. The temperature at this point, regardless of the reading on the different temperature scales, is called Absolute zero. Experiments have shown that for a perfect gas, this point of zero gas pressure is 273.1° C. below the melting point of ice. On the Fahrenheit scale it is 491.6° F. below that point, or 491.6° − 32° = 459.6° F. below zero Fahrenheit. A temperature of 60° F. computed from zero Absolute becomes 60° + 459.6° = 519° F. Absolute.

The Absolute temperature should always be used in formulas for determining pressures, volumes and temperatures of gases, as it corresponds with the point of zero gas pressure. Temperatures read from the Absolute zero are designated by capital letters, as T_1, T_2. Ordinary Fahrenheit temperatures are indicated by small letters as t_1, t_2.

77. Mechanical Equivalents of Heat. The units of quantity of heat are more readily understood when compared to mechanical or electrical units of energy. Joule experimented, by rotating paddles in a vessel of water so that the energy imparted to the paddle and the temperature rise of the water were measured. The relation between the two was found to be such that 778 ft.-lb. of mechanical energy were equivalent to 1 B.t.u. of heat energy. This unit is sometimes called Joule's equivalent or the *mechanical equivalent of heat.*

One horsepower is equal to 33,000 ft.-lb. per min., so, since 778 ft.-lb. equal 1 B.t.u., one hp. will be equal to $\frac{33{,}000}{778}$ or 42.4 B.t.u. per min., or $42.4 \times 60 = 2545$ B.t.u. per hr.

78. Specific Heat. The *specific heat* of a solid or liquid is the ratio of the number of B.t.u. required to raise a unit weight of the substance 1 degree compared to the number of B.t.u. required to raise the same weight of water 1 degree.

$$\text{Specific heat} = \frac{\text{B.t.u. to raise 1 lb. of substance } 1^\circ \text{ F.}}{\text{B.t.u. to raise 1 lb. of water } 1^\circ \text{ F.}}$$

Since the number of B.t.u. necessary to raise one pound of water 1° F. is one, the specific heat of any substance can be stated as the B.t.u. required to raise one pound of the substance 1° F. One B.t.u. will raise one pound of lead 33° F., one pound of aluminum 4.7° F., one pound of

ice 2° F., one pound of water 1° F. Different substances have different capacities for absorbing heat.

Specific heat of liquids or solids is not a constant. It varies when the temperature rises, or when a change of state, crystalline structure or density takes place. Thus carbon, in the form of charcoal, has a specific heat of .242; carbon in the form of a diamond has a specific heat of .105. This shows the variation in crystalline structure. The variation of specific heat with temperature range is small unless the temperatures are high. For this reason and due to the fact that the true values are uncertain and lead to complex problems, constancy of specific heat will be assumed over all temperature ranges. Pressure changes also cause a slight change in specific heat of solids and liquids.

There are two specific heats of gases. Specific heat at constant volume (C_v), is the heat necessary to raise one pound of the gas 1° F. without change of volume. Specific heat of a gas at constant pressure (C_p) is the heat required to raise one pound of gas 1° F. without change of pressure.

The fact that there are two specific heats can be easily explained. When a gas is heated at constant volume all the heat is used to produce a rise in temperature. When a gas is heated at constant pressure some of the heat is used to raise the temperature and some to expand the gas, in other words to increase its volume. The increase in volume causes the gas to do external work. Therefore the specific heat of a gas at constant pressure is always greater than the specific heat at constant volume. For air C_v = .169 and C_p = .237

The following table gives the specific heat of some of the common solids, liquids and gases.

TABLE VI.—SPECIFIC HEAT CHART

Solids		Liquids		Gases	C_v	C_p
Iron	0.110	Water	1.0	Air	0.169	0.237
Copper	0.093	Gasoline	0.700	Hydrogen	2.81	3.41
Aluminum	0.218	Kerosene	0.500	Ammonia	0.391	0.508
Tin	0.055	Mercury	0.032	CO_2	0.168	0.216
Zinc	0.094	Turpentine	0.472	CO	0.173	0.242
Ice	0.504	Machine oil	0.400	Nitrogen	0.173	0.244
				Oxygen	0.155	0.217

Vaporization

79. Heat Effects on Matter. Matter can exist in three states, namely as solid, liquid or gaseous. For instance, water may exist as ice, water, or steam and iron may exist in a molten, liquid or solid state. The ap-

plication of heat makes a change from one state to another possible, but there are many substances such as wood and other vegetable matter which can exist in one state only. In this case, the addition of sufficient heat to cause a change of state, will cause a decomposition of the substance. Lard, for instance, can easily be melted but if heated to too high a temperature, giving off ill smelling gases and leaving, as a residue, a porous mass of carbon. Gases can usually be changed, to a liquid state, and liquids to a solid state if reduced sufficiently in temperature. The addition of 1 × 32 × .5 or 16 B.t.u. to one pound of ice at zero degrees Fahrenheit, will raise the temperature to 32° F., but not further increase in temperature will take place. The addition of more heat will simply change the state of the mass from solid to liquid, that is the ice will melt and form water. Adding 1 × (212 − 32) × 1 or 180 B.t.u. will raise the temperature of the water to the boiling point but no further increase in temperature will take place. As in the first case the addition of heat will change the state of the water from liquid to gaseous, the new state being called steam. After the water has been changed to steam, the temperature will rise about 2 degrees for every B.t.u. added. The heat necessary to raise the temperature is known as *sensible* heat and that necessary to change its state is called its *latent* heat.

80. Latent Heat. About 144 B.t.u. are necessary to change one pound of ice at 32° F. to water at 32° F. This heat is called the *latent heat of fusion.* About 970 B.t.u. are necessary to change one pound of water from 212° F. to steam at 212° F. This heat is known as the *latent heat of vaporization.*

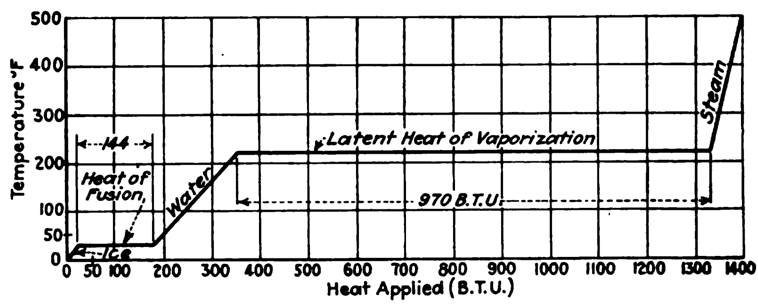

FIG. 73.—Three states of water.

Fig. 73 shows graphically the foregoing discussion.

Pressure changes effect the specific heat of solids, liquids and gases, but the effect is most noticeable on gases. Pressure changes also effect the latent heat of fusion and the latent heat of vaporization. The effect is more noticeable on the latent heat of vaporization. Great variations in pressure are necessary to cause even a slight change in the latent heat of fusion, but a pressure change from 14.7 lb. per sq. in. to 29 lb. per sq. in. will vary the latent heat of vaporization from 970.4

B.t.u. per lb. to 946.1 B.t.u. per lb. It is, therefore, evident that an increase in the pressure will cause a decrease in the latent heat.

81. Boiling Point. Although not a perfect definition of the boiling point, the following has been found to convey the desired idea satisfactorily. The maximum temperature which a liquid attains before changing to a gas is known as its boiling point at that pressure. A decrease in the pressure means a decrease in the maximum temperature which the liquids will attain, or a decrease in its boiling point. Therefore, the greater the altitude the easier it will be to bring the liquid to the boiling point or to the temperature where a rapid change in state will take place. The conclusion should not be drawn from this that the greater the altitude the easier to change liquid fuel to vapor state. This point will be discussed later.

Every liquid possesses a boiling point at a given pressure. Thus alcohol (ethyl) boils at 172° F., water at 212° F., and lead at 3272° F., at 14.7 lb. per sq. in. pressure. They are called *simple liquids* because their boiling point is fixed, that is they have only one boiling point.

82. Gasoline. Liquids, like gasoline and kerosene, however, are called *complex liquids* because they have no fixed boiling points. To prove this determine the boiling point of a sample from a can of gasoline. Allow the remainder to stand undisturbed for some time and when the test is repeated it will be found that the latter test shows the higher boiling point. Thus, since a variation exists, it is impossible to speak of a definite boiling point of gasoline. The end points, that is the lowest and highest boiling temperatures give a good idea of the quality of the fuel.

The latent heat of a simple liquid is a fixed quantity at a given pressure, but not so with a complex one. It is impossible to state definitely the latent heat of gasoline. The average latent heat usually is considered correct, and this varies from 150 to 190 B.t.u. per lb. or an average of 170 B.t.u. per lb. Although this quantity is variable, for calculations during this course the above-mentioned average value will be used.

It must be clearly understood that vaporization of gasoline means the changing of the liquid to a gas and the only method of obtaining this change is by the addition of the latent heat of the fuel. When a liquid is placed upon a stove it will vaporize rapidly because its latent heat is supplied from the fire. A cake of ice in the refrigerator will thus change its state, because its latent heat is supplied, not from a fire but from the food and air in the box. The absorption of this heat by the ice causes a lowering of the temperature of the air and food. The same conditions are present in the intake manifold of a gasoline engine. When the liquid fuel from the carburetor enters the incoming air as a fine spray, a large fuel surface is presented and the fuel takes its latent heat, which is necessary for vaporization from the air. As was the case in the ice

box, this removal of heat causes a decrease in the temperature of the air. The amount of this drop in temperature is dependent upon the ratio of air to fuel and to fuel used. It is approximately 40° F., varying only a few degrees either way if vaporization is complete. If only half of the fuel is vaporized the temperature will drop only 20° F. The following figures are based on a fuel with a latent heat of 170 B.t.u. per lb. and an air and fuel ratio of 15 to 1.

If 1 lb. of fuel is raised 1° F., .5 B.t.u. must be added.

If 1 lb. of air is raised 1° F., .25 B.t.u. must be added.

If 15 lb. of air are raised 1° F., 3.75 B.t.u. must be added.

If 16 lb. of mixture is raised 1° F., 4.25 B.t.u. must be added.

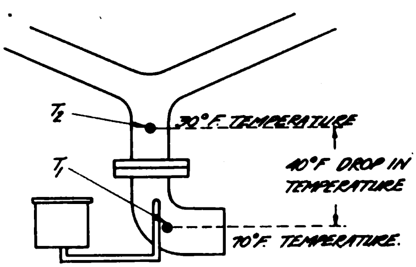

FIG. 74.—Temperature drop in the intake manifold.

The specific heat of the fuel is .5.

The specific heat of the air is .25.

Mixture means the air plus the fuel.

If 16 lb. of mixture decreases 1° F., 4.25 B.t.u. will be released, and if 170 B.t.u. are necessary for complete vaporization the 16 lb. of mixture must decrease $\frac{170}{4.25}$ or 40° F.

This temperature drop takes place between the point below the spray jets in the carburetor and the intake manifold. If thermometers are placed as shown in Fig. 74, the difference in the temperatures will be an indication of the drop.

Combustion

83. Mixture Composition. Three things are necessary for combustion in an engine cylinder, fuel-vapor, oxygen and heat. If these three are present in the proper proportions, combustion will take place. Usually more or less difficulty is experienced in obtaining the correct, proportions but the fuel-vapor presents the great problem in starting, especially with the heavy fuels in cold weather.

The liquid fuels, used in internal-combustion engines, are all hydrocarbons. That is, they are composed of carbon and hydrogen, the only difference that exists in the fuel being in the ratio of the carbon to the hydrogen. When speaking of gasoline the formula C_6H_{14} is usually thought of, but actually there is very little C_6H_{14} present, it being composed of C_8H_{18} and $C_{10}H_{22}$. To express this relation by a general formula, fuels are C_xH_y and different fuels vary only in the values of X and Y. The formula C_6H_{14} means that the proportion of carbon molecules to hydrogen molecules is 6 to 14. But inasmuch as carbon is 12 times as heavy as hydrogen this fuel is composed of 16 per cent. hydrogen and 84 per cent. carbon by weight.

Oxygen is necessary for combustion and about 3.75 lb. is required for every pound of gasoline burned. Since the air is composed of 23 per cent. oxygen and 77 per cent. nitrogen by weight, it is necessary to supply $\frac{.375}{.23}$ or approximately 15 lb. of air to every pound of gasoline that enters the engine.

The mixture of fuel with the combustion supporting agent which is oxygen, is known as the combustible mixture. Everything in excess is known as the neutral mixture. The neutral mixture is composed of the nitrogen which entered with the oxygen, the burned exhaust gases remaining in the cylinders and any excess of either fuel or oxygen. If 15 lb. of air is mixed with 1 lb. of fuel and the air is 235 oxygen by weight, the combustible mixture is one pound of fuel plus $.23 \times 15$ or 3.45 lb. of oxygen making 4.45 lb. The neutral mixture is $16 - 4.45$ or 11.55 lb. of nitrogen. If 1½ lb. of fuel is supplied, the combustible mixture is still 4.45 lb. but the neutral mixture is composed of 11.55 lb. of nitrogen plus the ½ lb. of fuel which was in excess of the required amount. In the same way, if excess air was supplied, the neutral mixture would be the nitrogen plus the excess oxygen.

84. Inflammation. The igniting of the particles of the fuel or the traveling of the flame through the mixture is called *inflammation.*

Combustion is the chemical combination of the fuel with the oxygen, caused by the application of heat.

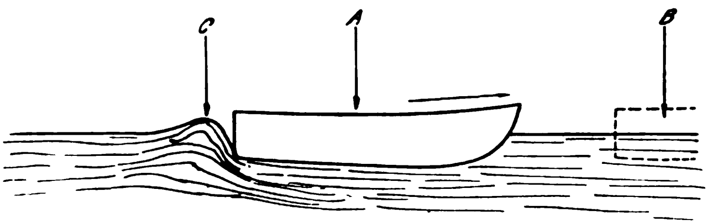

FIG. 75.—Comparison of inflammation and combustion.

Inflammation precedes combustion and the maximum pressure rise is attained at the end of the process of inflammation. It should be thoroughly understood that combustion may or may not be complete at this time. Combustion cannot start until after the mixture is ignited, although, if conditions are perfect, combustion will follow closely upon inflammation. Inflammation might be likened to a boat moved through the water and combustion to the wave which follows it. See Fig. 75. When the boat *A*, in Fig. 75, reaches position *B* the wave *C* may or may not be directly behind it.

The rate of flame travel or rate of inflammation varies, and is dependent on both the fuel and other factors which will be discussed later. If the rate of travel is moderately fast, it is known as inflammation

but under certain conditions a sudden increase of compression will ignite the entire charge at the same instant and give rise to what is known as *detonation*. When gun powder is ignited it burns, that is, each particle is set on fire by the burning of the one next to it. When dynamite is exploded the entire mass undergoes chemical action at the same moment and it is said to detonate.

Under certain conditions a partial detonation occurs in the engine cylinder. If a complete detonation occurred the engine cylinder would very probably be damaged. When there is an excess of carbon and deposit in the cylinder and the engine is sufficiently hot, a compression wave may be set up by the compression of the gases by the spark plug or by contact with the hot carbon particles. The presence of the carbon simply raises the temperature of the gases in the cylinder which increases the liability of detonation. When the hot gas is brought in contact with the red hot carbon particles the heat of the carbon may cause pre-ignition. This causes exceedingly high pressure with the resultant bearing knock which accompanies it. The wave may travel all the way across the cylinder or only part of the way, and will travel at various rates of speed giving pressures of various magnitudes.

Various mixtures and fuels have different properties for detonation. For instance a weak mixture or one composed of heavy fuels like kerosene detonates very easily. Knocks, which are very apparent with a weak mixture, can often be entirely eliminated by adding more fuel. This is very apparent when an engine is carrying too high compression. An engine may operate very well with a gasoline-air mixture, but if only a slight amount of acetylene (C_2H_2) is introduced into the fuel, knocking, caused by detonation, starts immediately. The presence of inert gases in the mixture, especially nitrogen, greatly reduces the liability of detonation.

85. Flame Propagation. Hydrogen has a much higher rate of flame travel than carbon and, therefore, a fuel high in hydrogen such as C_6H_{14} has a much higher rate of flame propagation than one low in hydrogen, such as $C_{20}H_{42}$.

The greater the pressure in the cylinder the closer the molecules of fuel will be associated and the easier the heat will be transmitted from one molecule to the next. A high pressure, therefore, is desired in order to obtain a maximum rate of flame travel.

A high temperature of the mixture is desired, because, if the mixture is at a low temperature, it must necessarily be increased until it reaches the ignition point before the flame will travel through it. This is illustrated in Fig. 76. *A* represents the spark plug; *B*, *C*, *D*, molecules of fuels at a temperature of 200° F. A spark is applied at *A* of sufficient intensity to ignite the fuel molecules *B*, but before fuel *C* and *D* can be ignited they must be increased 800° F., to bring them to the ignition point.

This takes time and consequently reduces the rate of flame travel. Had the temperature of the fuel been 800° F., it would require only an increase of 200° F. to reach the ignition temperature and this saving of time would have increased the rate of flame travel. A correct air-fuel vapor varying the *mixture ratio*, will cause a variation in the

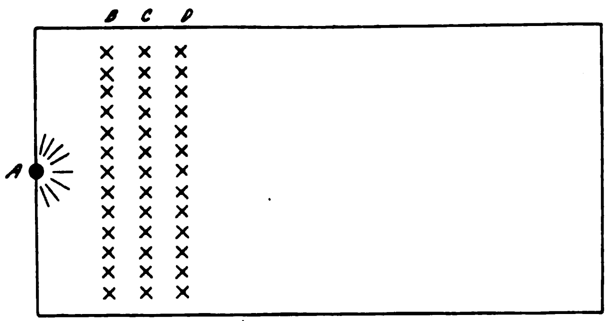

Fig. 76.—Flame propagation in cylinder.

rate of flame travel ratio gives the maximum rate of flame-travel and it is usually assumed that a slightly rich mixture is necessary to obtain the maximum rate, but the discrepancy comes from the distinction between air-fuel-vapor ratio and the air-fuel ratio. Inasmuch as the fuel is very seldom completely vaporized, the proportions supplied by the carburetor must be rich in order that the air-fuel-vapor ratio may be correct, as it enters the cylinder.

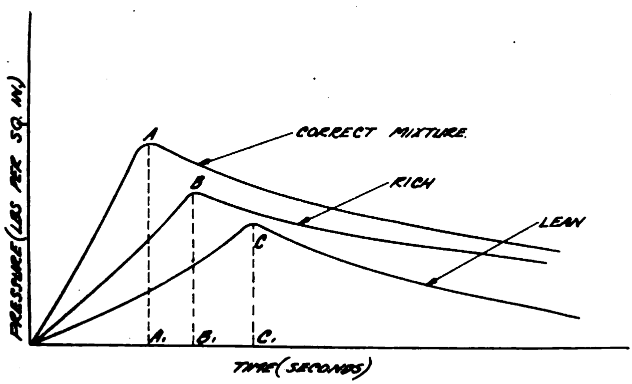

Fig. 77.—Rate of flame propagation.

A rich mixture (air-fuel-vapor) slows down the process of combustion and causes a decrease in the pressure and temperature resulting from it. A lean mixture has the same effect. Shown by Fig. 77.

The correct mixture attains a higher pressure and requires a shorter time to reach this pressure than either the rich or lean mixture.

Homogeneity signifies having the same properties or characters in every direction. A homogeneous mixture is one of uniform composition throughout so that samples taken from any parts of the mixture are exactly alike. Another way of expressing this is to say that the fuel-vapor is uniformly distributed throughout the air, so that if the properties in one part of the mixture are 15 to 1, it will be 15 to 1 in all parts of the mixture. Homogeneity is desired in order to obtain a uniform rate of flame propagation.

Neutral dilution has various effects on engine operation, sometimes being an aid but usually it acts as a hinderance to the effective performance of the engine. The presence of a neutral mixture lessens the charge weight of combustible material drawn into the cylinder and therefore lessens the power developed in the engine.

To obtain the maximum rate of flame propagation, pressure and temperature rise, all of which are essential in aircraft engine work, the following specifications are necessary:

High compression pressure.

High temperature of the gases at the end of compression.

Homogeneous mixture.

Correct air-fuel-vapor ratio.

Minimum amount of neutral dilution.

The higher the rate of flame propagation the higher will be the pressure and temperature of the gases. Such conditions are present when the air-fuel-vapor ratio is correct and the cylinder walls and gases are at a maximum temperature. Therefore, contrary to general impression, the exhaust valves do not reach their maximum temperatures with a slow burning mixture; but with a mixture of correct proportions. The burning of the valves takes place with a lean mixture, which is also slow burning. These two statements are not contradictory although they may appear so.

In oxy-acetylene cutting the temperature of the metal is first raised to the melting point by a pre-heating flame and then pure oxygen is applied directly to the heated part. The result is very rapid oxidization, which cuts the metal at a high rate. When an exhaust valve is heated to a higher temperature and free oxygen passed over it, as is the case in a lean mixture, the two unite and oxidization of the metal takes place, causing pitting and burning of the valves.

The exhaust pipe will heat when the mixture is slow burning because the gas continues burning until after the exhaust valve has opened and so retains a higher temperature than normal it enters the exhaust manifold. A rich mixture usually causes the manifold to heat more than a lean one.

When the mixture is extremely lean, it will be very slow burning and, if still burning when the inlet valve opens on the following intake stroke,

it will ignite the incoming charge, causing the flame to travel down the inlet manifold to the carburetor. The inevitable result is what is known as backfire.

Figure 7 shows an ideal indicator card in which the explosion or burning takes place instantaneously from *C* to *D* when the piston reaches the top dead center on the compression stroke. Such a card is not desired, for if the maximum pressure rise were attained with the piston at top dead center, it would result in a bearing knock and a reduction in power output. The maximum pressure rise should occur just after the crank has passed top dead center and the piston started on its downward stroke. Such a piston position is shown in Fig. 178, and the corresponding point on the indicator card at *D* in Fig. 79.

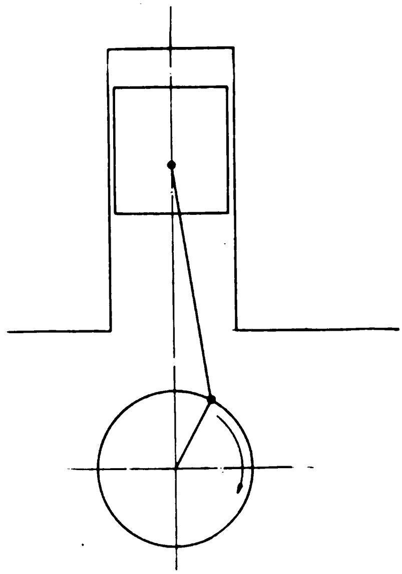

FIG. 78.—Exaggerated position of crank when maximum pressure rise should occur.

These figures are exaggerated to facilitate interpretation. In order to get the maximum pressure at *D*, the charge must be ignited before the piston reaches the end of the compression stroke. Such a position is shown by the point *C*.

The point of maximum pressure is all important and, therefore, the end of the combustion process is more important than its beginning. With this as a basis the point of ignition should be varied to obtain the most effective results.

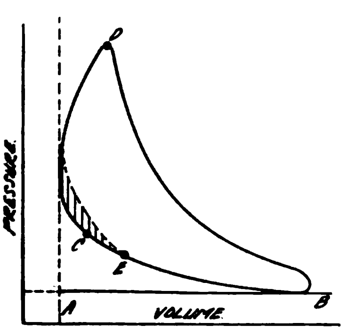

FIG. 79.—Exaggerated indicator card.

A slow burning mixture will require a longer time to burn, and, therefore, the charge must be ignited earlier, as illustrated by the point *E* in Fig. 79. This will give the desired results, but usually will cut off a corner of the indicator card as shown by the shaded portion, Fig. 79. Increasing the spark advance is not a remedy for slow flame propagation. The real remedy is better mixture quality.

86. Ignition Temperature and Experimental Determination. The ignition temperature for different fuels is a variable quantity, depending upon the fuel, air-fuel ratio, degree of homogeneity, and other like factors.

The variation is so great that no definite value can be assigned to it. For most gasoline-air mixtures the ignition temperature is in the neighborhood of 1000° F., perhaps a little below this figure.

Falk's method for determining the ignition temperature consists of very rapidly decreasing the volume of a quantity of fuel mixture in a cylinder with consequent increase in pressure and temperature until

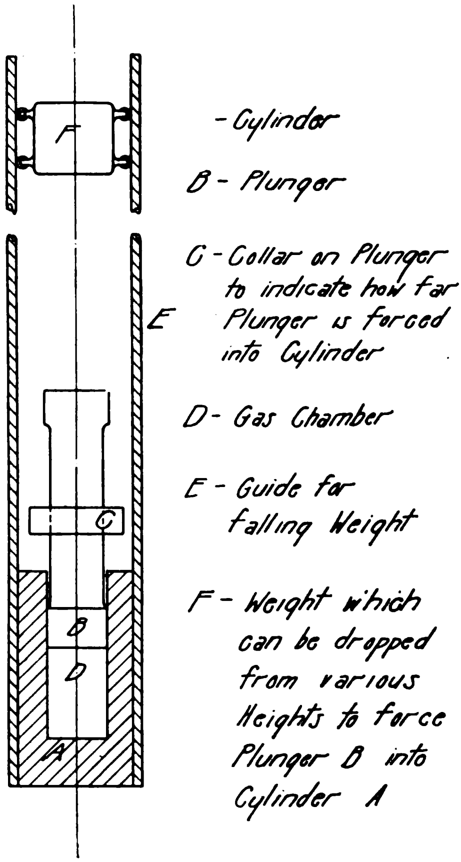

FIG. 80.—Falk's apparatus.

ignition occurs. By noting the volume decrease, the resulting temperature is computed from the formula, $T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{s-1.}$ Figure 80 illustrates the apparatus used in this experiment.

The plunger B, when struck by the falling weight F, compresses the charge. Nearly instantaneous compression results and therefore, the adiabatic formula may be applied. The average ignition temperature as determined by experiment with many samples of gasoline mixed in the proper proportions, is 986° F., but it must be emphasized that this value

was obtained while the combustible mixture was under a high compression. The mixture in actual practice is very seldom perfectly homogeneous or in the correct proportions, and therefore, it would require a higher ignition temperature. As a result of these experiments, it seems reasonable to state that the ignition temperature of gasoline in actual practice is over 1000° F.

87. Heat Value of a Fuel. The heating value of a fuel is the number of B.t.u. it contains per pound. This value may be obtained in two ways, either experimentally or by use of a formula. All formulas are empirical and are based on experiments. Figure 81, represents a bomb calorimeter, an instrument for determining the heating values of fuels. For convenience the size of the apparatus is represented much larger than normal proportions.

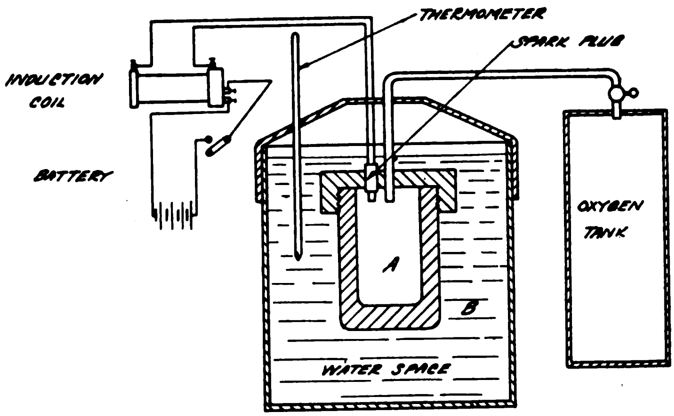

FIG. 81.—Bomb calorimeter.

A is a box holding one pound of fuel vapor plus the necessary amount of oxygen for complete combustion and is built sufficiently strong to withstand the explosion of the charge. *A* is placed in the container *B* which is filled with 200 pounds of water to entirely cover the box. To conduct this experiment, the temperature of the water in container *B* should be noted, which, for the purpose of illustration, we will assume as 60° F. The charge is ignited and the water kept in motion. Immediately the temperature begins to rise and when it has reached its maximum height the temperature should again be noted. Assume that the temperature has advanced to 160° F. which is a rise of 100° F.

One pound of water raised one degree requires one B.t.u.

One pound of water raised 100 degrees required 100 B.t.u.

200 pounds of water raised 100 degrees require 20,000 B.t.u.

or $H = C(t_2 - t_1)W$

$= 1(160 - 160)\,200$

$= 20{,}000$ B.t.u. the heating value of one pound of fuel.

Assuming that the fuel was C_9H_{20} it contains about .16 lb. of hydrogen and .84 lb. of carbon. The hydrogen unites with oxygen, forming H_2O which has a latent heat of 970 B.t.u. per lb. None of the gases could escape from the container and therefore, when the temperature due to combustion receded, the steam condensed and gave up its latent heat. This one pound of fuel contained .15 lb. of hydrogen which unites with 1.2 lb. of oxygen making 1.35 lb. of water vapor. Therefore, $1.35 \times 970 = 1300$ B.t.u. released as latent heat. The difference between the heating value obtained by the calorimeter and the latent heat of the water formed is known as the *lower heating value.* The larger quantity is the *higher heating value.*

88. Temperature Rise. Since it is necessary that the gasoline-air mixture reach a temperature of 1000° F. before combustion will take place, the factors which help to raise the mixture to this temperature should be considered.

First, the fixed compression volume ratio of an engine cylinder determines the temperatures to which the gases will be heated by compression. The compression pressure must be held below that point at which the charge will ignite itself, and so controlled that it may be varied by changing the time of the spark.

Second, the presence of carbon particles will raise the temperature, locally, many times above the point of ignition. This causes ignition of the charge and the result is known as a carbon knock. If the temperature due to compression is not too high, a great amount of carbon is necessary before preignition will occur.

Carbon is a very poor heat conductor and, therefore, even though the cylinder walls are cold and the layer of carbon thin, the carbon will reach a very high temperature because of its inability to transmit the heat rapidly. As a result of this, the charge may be ignited prematurely, when it comes in contact with the hot carbon.

It has been proven by experiment, that 750° F. is the maximum safe temperature for the gases at the end of compression. If the temperature is higher, preignition will occur. Therefore, if the compression-volume ratio is sufficient to raise the gases to this temperature with a normally hot cylinder, an abnormally hot cylinder caused by the pressure of carbon, will produce a carbon knock. The remedy is to remove the carbon or reduce the compression.

Preignition seldom occurs much earlier than 15° B.T.C. and as this is the usual spark advance for slow speed operation, if an excessive amount of carbon is present, preignition will occur. When operating at high speed the normal spark advance, is 30° B.T.C. and if preignition due to carbon, occurs between 15 and 30 degrees advance, no trouble will be experienced as the effect will not be as pronounced as a low speed.

Experiment has proved that the higher the compression the higher

will be the thermal efficiency. Therefore, high compression is desirable to obtain high thermal efficiency and on the other hand low compression, will eliminate carbon troubles. As a natural conclusion it becomes necessary to choose the highest compression which will be consistent with freedom from carbon troubles. This compression will vary with operating conditions. An engine, designed for high speed and high altitude work, must have the maximum compression pressure, while a machine operating at sea level must have a lower compression. A slow-speed stationary engine, which is expected to operate for long periods with minimum attention, must be of the low-compression type.

The theoretical pressure and temperature derived from combustion can be obtained from the formulæ

$$H = C(t_2 - t_1)W \text{ and } P_2T_1 = P_1T_2$$

but the results obtained are much higher than are actually realized. Average heating values for fuels substituted in the above formulas show a temperature rise of about 7000° F., but 3500° F. is the actual maximum rise. There are many theories advanced to explain why the computed temperature is not obtained. The most notable theory presents the explanation, that, as the pressure rises the specific heat of the mixture increases, thereby requiring more heat to raise the temperature. This is partly true, but it does not entirely explain the great discrepancy. Other theories presented are described in Judge's "High Speed Internal Combustion Engines," p. 117.

It has been found, that, if the computed temperature rise is multiplied by .5, the approximate correct result will be obtained.

Example. Determine the actual temperature rise with a fuel having a heating value of 20,000 B.t.u. per pound. If one pound of fuel is mixed with 15 pounds of air, and burned at constant volume.

Formula

$$t_2 - t_1 = \frac{H}{W \cdot C_v} = \frac{20{,}000}{16 \times 17}$$

$= 7300°$ F. theoretical temperature rise.

where, $t_2 - t_1$ = temperature rise in degrees Fahrenheit.

H = Heating value of one pound of fuel in B.t.u.

W = Total weight of the mixture (fuel plus air).

C_v = Specific heat of the mixture at constant volume.

The actual equals .5 of the theoretical.

Therefore $.5 \times 7300 =$ 3650 °F. Actual temperature rise.

Data

$t_2 - t_1 = ?$

$H = 20{,}000$

$W = 16$

$C = 17$

Heat Transfer

89. Convection. The carrying of heat by circulating means. When the bottom portion of a fluid receives heat energy from some outside source, a small portion nearest the source becomes warmer and less dense than the remainder of the liquid. Due to this it travels upward to the top of the liquid and the cooler portion travels toward the bottom and in turn becomes warmer and thus the whole liquid becomes heated. As a practical test of convection, an ordinary test tube is filled with water and a small piece of ice held in the bottom of the tube. Heat is applied at the top of the liquid and practically all of the water will evaporate before the ice starts to melt.

If the heat however, is applied at the bottom of the tube the ice will melt quickly. This shows that the heated portion, because it becomes lighter than the surrounding fluid, always travels upward and the cool portion travels downward because it is heavier than the heated portion.

90. Conduction. The process of transferring heat energy from one part of a body to another without any motion of the parts of the body is called conduction. Conduction is very different from convection. If heat is applied to one end of a rod the energy passes from layer to layer by contact until it reaches the other end. As an example, if one end of a metal rod is put into a fire and the other end held in the hand. In a few minutes the hand will become very warm. The rate of transfer of heat energy differs for every material. Conduction might be better understood if certain conditions are assumed. Suppose a sheet of metal of uniform thickness separates a region of high temperature t_1 from a region of lower temperature t_2. Now the amount of heat conducted through the metal will depend upon the following factors.

It will be in direct proportion to:

(*a*) The area of the conductor.
(*b*) The temperature difference between the two sides.
(*c*) A certain factor which shows the effect of the material used and its conduction power called the conductivity factor.
(*d*) Time.

It will be in inverse proportion to:

(*e*) The length of the path.

From the above it is possible to write the formula as:

$$H = \frac{KAZ\,(t_1 - t_2)}{1}$$ where,

H = total number of B.t.u. conducted per hr.
K = conductivity factor.
A = area of conducting material in sq. ft.

$(t_1 - t_2)$ = temperature difference in degrees F.
1 = length in feet.
Z = time in hours.

In the above formula, K is used as the conductivity factor.

The conductivity factor for any certain substance is the number of British thermal units transmitted per hour, per square foot, per foot of thickness per degree temperature F. difference between the two sides of the metal.

A few values of the thermal conductivities or K of several metals are given below.

Substance	Thermal conductivity
Aluminum	116.0
Copper	220.0
Iron	36.0
Steel	26.0
Lead	20.0
Mercury	4.0
Tin	36.0
Zinc	63.0
Brass	63.0

91. Radiation. The process by which energy is transmitted through space without the necessary presence of matter. Radiation always takes place in straight lines and has the property of passing through dry gases without heating them to any appreciable extent. When energy is transmitted this way it is called radiant energy and is not heat, since heat is energy in a particular relation to matter. By allowing the sun's rays to pass through a glass and fall upon a blackened thermometer, it may be very decidedly heated, though the glass remains cool, it is shown that energy may pass through matter and still not be heat. Another example is the sun's rays. The earth receives radiant energy from the sun and in turn heats up the surrounding atmosphere by convection. If the intervening space between the sun and earth were heated it would stand to reason that the nearer the sun the hotter it would be. This is not true, however, because at high altitudes it is very cool compared to the temperature of the air at sea level.

Radiant heat, like light, is reflected from various materials, and it will be found that in general substances possessing a high power of radiation have a low reflecting power.

To show how two bodies differ in reflecting power, take two parabolic mirrors Z and Y of the same size. At the same location from each mirror or reflector place two equal sources of heat. Have the surface of Z highly polished and the surface of Y unpolished. In measuring the intensity of reflected heat at A and B, which are in the same respective location, it will be found that at A it is much warmer than at B. In measuring

the temperature in the reflector at t_1 and t_2 t_2 will be the greater due to the fact that the unpolished reflector *Y*, absorbed more heat than the reflector *Z* which is highly polished. Light objects usually reflect heat while dark objects will absorb heat. This is also true of light and dark colors. The roofs of many houses have light colored tile, merely for the purpose of reflecting heat, so that it will not enter the house. Radiation travels with the same speed as light and it can be reflected by mirrors and refracted by lenses and prisms. It is now known to be a sort of wave disturbance similar to the waves that travel over a water surface.

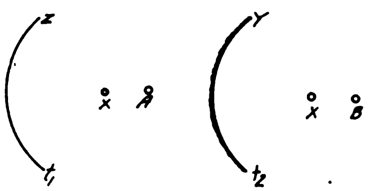

FIG. 82 —Reflection of heat.

In order to measure radiation it is converted into heat by absorption in matter, the heat being then measured by the temperature change which it produces. The action of a thermopile which is used for measuring radiant energy is not taken up here because it is too complicated for this work.

The general expression for heat given off by radiation is as follows:

$H = K\ (T_1^x - T_2^x)$ where, H = total heat in B.t.u.'s given off.
K = radiation coefficient.
T_1 = absolute temperature of hot body.
T_2 = absolute temperature of cold body.

In the formula X is taken as equal to 4 and K is taken as (16×10^{-10}) or $\left(16 \times \frac{1}{10^{10}}\right)$. The above formula is not used in the calculation in this source but is given merely to show how the total heat of radiation is figured.

92. Aircraft Radiators. The word radiator comes from radiation and should not be used when speaking of the cooling device of an aircraft engine. The heat is not taken away from the hot water by radiation but by convection and conduction. It is necessary for every type and design of engine to use a certain size cooling device which is called a radiator for want of a better term. Of the heat put into the engine a certain amount goes to the water jacket and the water has to be cooled in some way. This is done by allowing the water to circulate through the radiator and the heat from the water goes through the metal and is carried away by the air rushing through the radiator. Knowing the amount of heat or B.t.u.'s that have to be carried away, the actual size of the radiator in square feet of cooling surface can be figured. It should be clearly understood that by the term cooling surface is not meant the overall dimension of the radiator, but the actual area of metal surface exposed to the air currents.

$$A = \frac{H}{K(t_1 - t_2)} = \frac{540{,}000}{30 \times 100} = \frac{540{,}000}{3{,}000} = 180 \text{ sq. ft. of cooling surface.}$$

The following are values of K for the radiators of several aircraft engines.

Liberty Engine,	$K = 33$
Curtiss V2 Engine,	$K = 30$
Curtiss OXX6 Engine,	$K = 20$

The cooling surface in square feet for a cellular radiator is equal to the circumference of the tubes times the length times the number of tubes times the area of the fin.

Assuming that the air increases 40° F. in passing through the radiator, the average air temperature would be the initial plus the 20° F. so the value of t_2 in the above formula would be the average air temperature or the initial temperature plus the final temperature divided by two. For

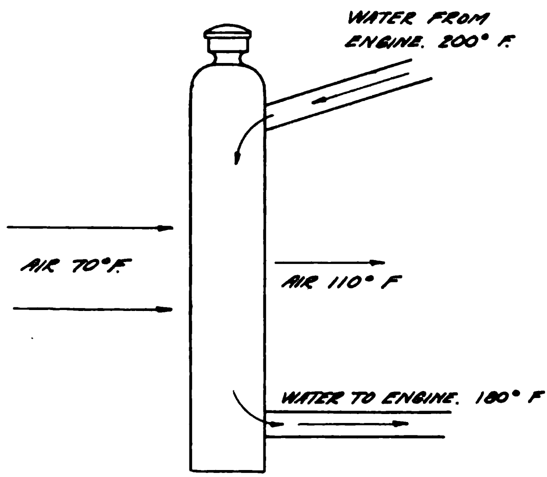

FIG. 83.—Radiator.

example, in Fig. 83, the temperature of air entering the radiator is 70° F. The temperature of air leaving the radiator is 110° F. The value of t_2 to employ in the formula this becomes $\frac{110 \text{ plus } 70}{2} = 90°$ F.

In the similar manner the average water temperature is calculated. Assuming that the water enters the cylinder jacket at 130° F. and goes to the radiator at 200° F., the average water temperature (T) would be 190° F. The temperature difference between the air and water which causes the heat to flow is equal to the difference in temperature between T_1 and T_2 or $190° - 90° = 100°$ F. The same formula may be applied to compute the heat transmitted through the cylinder walls to the water in the jackets. The heat flow is proportional to the temperature differ-

ence, and in the cylinder problem this is far greater than in the radiator problem.

A definite quantity of air is necessary to properly cool the water in the radiator. It is known that one-quarter of AB will raise one pound of air 1° F. at constant pressure. Thus, if one pound of air in contact with the radiator is increased one degree in temperature one-quarter of AB is extracted from the water. The amount of air necessary to carry away a certain amount of heat depends upon the specific heat of the air and the temperature of the air before and after passing through the radiator.

The formula is as follows:

$$H = C(T_1 - T_2)W$$

$$W = \frac{H}{C(T_1 - T_2)}$$

H = total heat in B transmitted per hour.
C = specific heat of air.
T_1 = temperature of air leaving radiator.
T_2 = temperature of air entering radiator.
W = pounds of air necessary.

Figure 84 is termed a heat flow diagram to graphically illustrate the relative resistance to heat flow offered by the water, water film, metal, air film, and air.

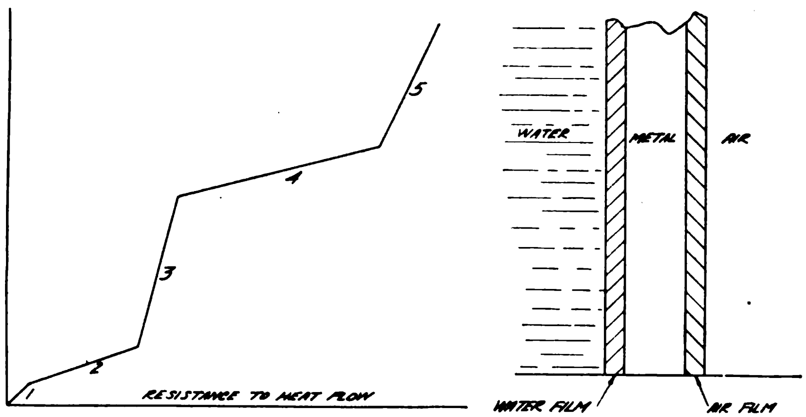

Fig. 84.—Heat flow through metal.

In Fig. 84:

1. = resistance of heat flow offered by water.
2. = resistance of heat flow offered by water film.
3. = resistance of heat flow offered by metal.
4. = resistance of heat flow offered by air film.
5. = resistance of heat flow offered by air.

This diagram shows that the resistance offered to heat flow by the metal is very small as to that compared to the water film and air film.

The air film is the limiting factor of heat flow and if this can be broken

down, the heat can flow much faster. Because of the low resistance to heat flow as compared to that offered by the air film the material of which a radiator is constructed has no material effect upon the rate of heat flow. A very high velocity of air is necessary so that the dead air film can be scrubbed away. If this is done the rate of heat flow will be much faster. This is also true of the water velocity up to a certain point. Above this speed no noticeable effect takes place. The radiator should be put in such a position that it will at all times have a very high air velocity through it.

When heat is applied to a metal definite changes in length and volume takes place and these cannot be resisted in any way. The tires of wagons and locomotive wheels are made too small to slip in place, and are then put on while expanded by heat, so that when cool and shrunk, they have a firm grip. If a hot shaft rotates in a cool bearing, the bearing will be ruined unless a clearance, between the shaft and bearing, has been allowed. It is necessary therefore to have a clearance between all moving parts when cold, where heat is generated, so that sufficient allowance will be given to prevent seizing, when at the operating temperature.

Expansion

93. Linear. The material, its length and temperature change all effect the expansion. For purpose of comparison and practical computation it is convenient to know the increase in length per unit length per degree of temperature change in different materials. A formula has been derived which gives the total expansion of a rod.

$$E = LK\,(T_1 - T_2)$$ where,

E = total expansion (same unit as L).
L = total length (usually in inches).
K = coefficient of linear expansion.
$(T_1 - T_2)$ = temperature difference.

In the above formula K is the coefficient of linear expansion, which is the increase in length divided by the original length, times the rise in temperature. Stating it in another way, it is the expansion per unit length per degree temperature difference. This quantity is usually determined for the range of temperature from the freezing point to the boiling point of water and the average value taken.

For an example of the determination of the rate of increase in length of a solid rod an application of heat to an aluminum rod will be taken. The length of the rod being 24.5 inches when its temperature is 70° F. By applying heat and raising the temperature of the rod to 215° F. and measuring the increase in length it is found that for a rise in temperature

of 215° F. −70° F. or 145° F. the rod expands .0439 in. From this data the elongation per inch per degree F. will be equal to .00179 divided by 145 or .00001235 in. This latter value is the coefficient of expansion of aluminum.

The coefficient of linear expansion per degree Fahrenheit for other metals is given below.

Substance	Value of K
Lead	0.00001624
Copper	0.00000928
Steel	0.0000063
Brass	0.0000107
Nickel	0.00000706

The coefficient of area expansion of any substance is equal to the increase in area divided by the original area and dividing the result by the rise in temperature. The coefficient of cubical expansion of any substance is equal to the increase in volume divided by the original volume and dividing the result by the rise in temperature.

From the above explanation of expansion of heated metal it can be seen that in order to have a correctly designed engine it is necessary to have the proper clearance between all parts that become heated during operation. In order to determine the proper clearances the temperature rise must be known because the expansion depends directly upon this. An oil film must be maintained at all times between moving parts and it is necessary to have the proper clearance and the correct lubricant.

When the piston and cylinder walls are of the same material it is easy to arrive at the correct clearance between the two. When, however, they are of different materials the expansion of the metal will be different. Furthermore it must be remembered that the cylinder walls are kept constantly cool by water. It is absolutely necessary to know the clearance when the pistons and cylinder walls are hot or at their working temperature. The clearance when cold is not so important but the clearance when the parts are hot must be known so that a definite oil film can be maintained between the parts. The clearance between aluminum pistons and steel cylinders is about double that for cast-iron because the coefficient of expansion of the former is almost twice that of the latter.

This same practice will hold good for bearings. An oil film must be maintained between the shaft and the bearings and it is necessary that there be a proper clearance between the two. The oil film between the valve stem and its guide is not so important, but the required clearance must be provided, so that the stem will not stick in the guide. This also holds true with the tappets. The clearance between the valve stem and rocker arms or tappets decreases in most engines having an overhead camshaft, when the engine becomes heated. When the camshaft is located in the crankcase, as in the case of the Sturtevant engine the

clearance increases when the engine becomes hot. This is due to the expansion of the cylinder and jacket which also carries the valve and rocker arm with it. The tappets remain cool and do not expand and thus the clearance always increases. The clearance required therefore will depend upon the total temperature, size, shape and length of material used.

Lubrication

94. Viscosity. Although the subject of lubrication has been covered in a previous lecture, it is desirable to emphasize several points at this part of the course.

The effect of temperature on lubricating oil is very important. An increase of temperature causes a decrease in the viscosity of the oil. Consequently the oil flows more freely as the engine becomes warmer during operation. In the selection of an oil for aircraft engine lubrication, therefore, the temperature at operation under unfavorable conditions must be considered. It is well in selecting a new oil to test the viscosity at various temperatures and to plot the results in graph form, viscosity versus temperature.

The adhesive property of different lubricating oils is quite different. Vegetable oils adhere more readily to metal surfaces than oils of mineral origin. This is one factor in favor of the use of castor oil rather than mineral oil in the engine of the rotary cylinder type, where the lubrication of the cylinders is a very difficult problem.

95. Gravity. In addition to the various oil tests which have been discussed, the gravity is usually measured. Gravity has no effect on the adaptability of an oil for lubricating purposes, but furnishes a means of checking the weight of oil purchased.

Pressure, Volume and Temperature Relations of Gases

96. Pressure vs. Volume. In a previous discussion it was shown that solids expand when heated. This holds true with gases also and the expansion and contraction of gases is far more noticeable than that of solids. Whenever the volume of a given weight of gas is decreased, there is always a definite increase in pressure and certain laws govern this phenomenon. The so-called perfect gases are those which obey very closely the laws of Boyle and Charles. The law of Boyle states, that when the temperature remains constant the product of the pressure and volume of a given weight of gas is a constant. In other words, $PV = P_1V_1 = P_2V_2 = \text{Constant}$.

It must be borne in mind that in all discussions of gases, only absolute pressures and absolute temperatures can be used.

97. Volume vs. Temperature. The law of Charles states that when the pressure of a given weight of gas remains constant the volume will

vary directly as the temperature. The two laws may be considered to give the following relation. $PV = \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3} = \text{Constant.}$

Expansion or compression of a gas in accordance with Boyle's Law requires that there be no change in temperature. This is known as isothermal expansion or compression.

In a gas engine, isothermal treatment of gases is impractical. Also, the gases employed are not perfect gases. To obtain isothermal compression of a gas it would be necessary to abstract the heat from the gas as rapidly as it is generated during compression.

98. Temperature vs. Pressure. If a gas could be compressed or expanded without allowing the gas to absorb or lose heat, the treatment of the gas would be adiabatic. The following relation would govern the gases, $PV^s = P_1V_1^s = P_2V_2^s = \text{Constant.}$

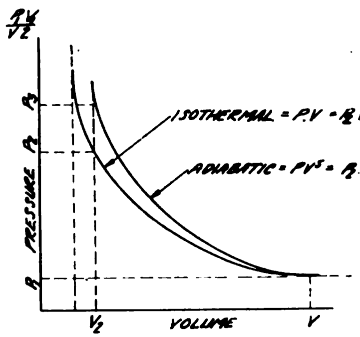

FIG. 85.—Compression.

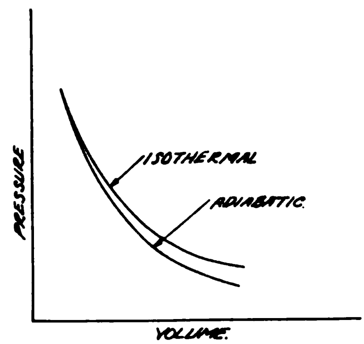

FIG. 86.—Expansion.

The exponent s is different for each gas. For adiabatic treatment of air $s = 1.41$. For carbon dioxide, s varies from 1.33 to 1.41. The pressure rise in adiabatic compression will be higher than could be obtained in isothermal compression, with the same volume of charge, because of the temperature increase, see Fig. 85.

Fig. 86 illustrates the more rapid drop of the adiabatic curve when a gas is expanding. Besides the adiabatic and the isothermal there are many other lines or curves that may be considered in a detailed study of gases, among them being constant pressure and constant volume lines. In this work the chief interest lies in the adiabatic for this most nearly represents the case of the gases in the cylinder during power and compression strokes as will be seen when the cycle of engine operations is considered.

The exponent s to be used for adiabatic treatment of a gas is obtained from the following relation. $s = \frac{C_P}{C_V}$ where C_P is the specific heat of

the gas at constant pressure and C_V is the specific heat of the gas at constant volume. For air $C_P = .238$ and $C_V = .169$ therefore;

$$s = \frac{C_P}{C_V} = \frac{.238}{.169} = 1.41$$

Ideal Cylinder Processes

99. Phase. A single process or operation is called a phase. Drawing the charge into the engine cylinder is one phase, compressing the charge would be another phase and so on until a new charge is drawn in.

100. Cycle. In a gas engine there is a series of operations consisting of suction, compression, expansion and exhaust, to which is termed a cycle of operations.

101. The Otto Cycle. All present aircraft engines operate on the Otto cycle, which is composed of the following four operations and which succeed one another in the order given: (*a*) admission of the charge to the cylinder, (*b*), compression of the charge, (*c*) combustion of the charge, which includes its ignition and expansion, and (*d*), exhaustion of the products of combustion from the cylinder. The majority of aircraft engines require four strokes of the piston for accomplishment of the cycle of four operations, and are called four-stroke-cycle engines. Some types of engines accomplish the cycle in two strokes and are called two-stroke-cycle engines.

102. Work Diagram. It has been shown that work is a product of force and distance or, of pressure and volume. The determination of cylinder pressure, by use of the indicator, has also been discussed. In analyzing indicator cards, it was shown that they show the relation between, cylinder pressure and cylinder volume at all stages of the cycle of operations, areas on a pressure-volume diagram representing work. In as much as an indicator card is such a diagram, its area represents the work done in the cylinder by the burning gases. Work done on the piston is called positive work and on the indicator card all the area under the expansion curve represents positive work. This is shown in Fig. 87.

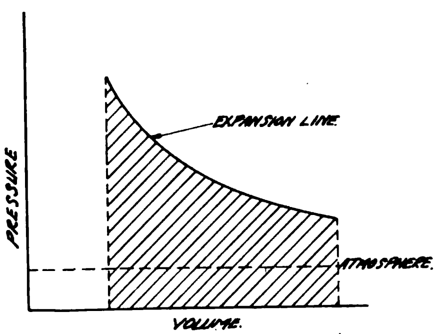

FIG. 87.—Work done during expansion.

All work which opposes the motion of the piston is called negative work. Thus on compressing a charge in the cylinder, the gas tends to oppose the motion of the piston and all work done on the compression stroke is considered as negative work, see Fig. 88.

The work done during the suction and exhaust strokes is neglected in this discussion because it is negligible as compared to the work done during compression and expansion. If the negative work is subtracted from the positive work, the net remainder will be the useful work, as shown in Fig. 89.

The cross-sectional area in Fig. 89, represents the net work done and it is the difference of the areas under the compression and expansion lines.

Computation of compression pressure. The compression of the charge approximates an adiabatic compression, the expression for which is $P_1V_1^s = P_2V_2^s$, where $s = \frac{C_P}{C_V}$. If P_1 is the pressure in the cylinder

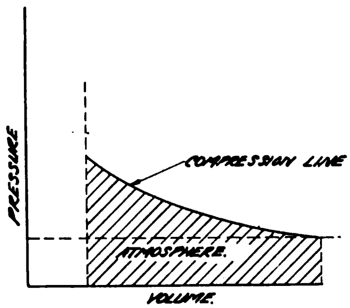

FIG. 88.—Work absorbed during compression stroke.

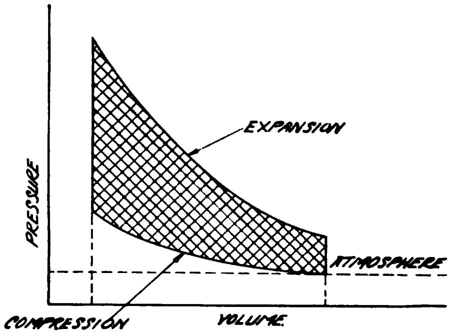

FIG. 89.—Net work of Otto cycle.

when the compression stroke begins and V_1 is the volume occupied by the gases at the beginning of the compression stroke (volume swept through by piston plus clearance volume) and P_2 the pressure at the completion of the compression stroke and V_2 the volume occupied by the gases at the completion of that stroke usually called clearance volume, then P_2 the compression pressure, is dependent upon P or the initial pressure.

The pressure at the end of the suction stroke P_1 is dependent upon several factors including piston speed, restricted passages, charge heating and atmosphere pressure or in other words it is dependent upon the volumetric efficiency. At low engine speeds the initial pressure is usually very close to atmospheric pressure or 14.7 lb. per sq. in. while at normal engine speeds this pressure is not more than from 12 to 13 lb. per sq. in. The ratio of $\frac{V_1}{V_2}$ is known as the **compression ratio.** The value of s, as determined from actual indicator diagrams, is about 1.33. For example assuming an initial pressure of 13 lb. per sq. in. and a compression ratio of 4 to 1, the final compression pressure will be $13 \times 4^{1.33} = 82.0$ lb. (Absolute) knowing the initial volume and pressure can be

found for any decrease in volume, with this formula. A good knowledge of logarithms is necessary, however, to work the problem. As one of the factors must be raised to some power S and this is only possible by their use.

Efficiencies

103. Mechanical Efficiency. Much of the total power generated by the expanding gases in the cylinder is lost in piston and bearing friction and valve operation. The output of the motor is equal to the input minus those losses. The ratio of the output to the input is termed the mechanical efficiency. That is

$$\frac{\text{Output}}{\text{Input}} = \text{Mechanical effieiency.}$$

The efficiency is usually about 75 to 85 per cent. The following expressions define mechanical efficiency.

$$\text{Mechanical efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{b.hp.}}{\text{i.hp.}} = \frac{\text{b.m.e.p.}}{\text{i.m.e.p.}}$$

where, b.hp. = brake horsepower.
i.hp. = indicated horsepower.
b.m.e.p. = brake mean-effective pressure.
i.m.e.p. = indicated mean-effective pressure.

104. Thermal Efficiency. It is possible to express thermal efficiency either as brake thermal efficiency or indicated thermal efficiency because there is a direct relation between the two. The indicated thermal efficiency is the ratio of the heat actually made available by combustion in the cylinder to the heat in the fuel supplied to the cylinder. The brake thermal efficiency is the ratio of the heat equivalent of the energy available at the flywheel of the engine, to the heat contents of the fuel actually supplied the cylinder.

$$\text{Brake thermal efficiency} = \frac{\text{B.h.p. output}}{\text{Fuel input}} = \frac{2{,}545}{hw}$$

where, w = fuel used per b.hp. per hr.
h = heating value of 1 lb. fuel.

The indicated thermal efficiency may be determined by dividing mechanical efficiency into brake thermal efficiency.

$$\text{Indicated thermal efficiency} = \frac{\text{B.hp. output}}{\text{Fuel input}} = \frac{\text{brake thermal efficiency}}{\text{mechanical efficiency}}.$$

As the speed of a gasoline engine is increased to a certain limit, the thermal efficiency increases. Operating the engines with a closed throttle causes a lowering of the compression pressure and also lowers the thermal efficiency. The charge density is also reduced. On the other hand, when the engine is running at a high speed, the periods for charging,

compressing and exploding the mixture will be shorter and the heat exchange between the charge and cylinder walls will be smaller than in a slow-speed engine. At high temperatures the incoming charge is heated and this carries a falling off in the charge weight and a tendency toward preignition. Generally speaking, the best thermal efficiency is obtained at some point before the maximum speed of the engine is reached, so that at this speed the thermal efficiency and therefore the fuel consumption per brake-horsepower per hour will be lowest.

The heat from the explosion is transferred through the cylinder walls to the water by conduction. The total heat conducted depends directly upon the temperature difference, $t_2 - t_1$. At slow engine speeds the gases are exposed to the cylinder walls longer and more heat will go to the water and the thermal efficiency will be lower. It is known that a hot cylinder wall will give a better thermal efficiency than a cold one but after this exceeds a certain temperature the efficiency falls off.

A series of experiments were conducted at Columbia University to determine the effect of cylinder wall temperature on the heat lost to the water and the thermal efficiency. There was only a slight difference noted but the advantage was in favor of the hot walls due probably, to a better drying of the mixture. The thermal efficiency and the jacket losses will both be effected with the details of design.

105. Air-card Efficiency. A standard reference card is used in gasoline engine work and is assumed as that indicator card which would result if pure air passed through the four phases of an ideal cycle, receiving the same amount of heat per pound of air working as does the pound of air-gas mixture in its combustion. This air-card efficiency is a theoretical efficiency which is never equalled in actual engines. This ideal efficiency really represents the maximum possible efficiency that could be obtained, theoretically, from the engine when using the given compression ratio.

Below will be given the different efficiencies with their relation to pressure, volume and temperature ratios.

$$\text{Efficiency} = 1 - \left(\frac{P_1}{P_2}\right)^{\frac{S-1}{S}} = 1 - \left(\frac{V_2}{V_1}\right)^{S} = 1 - \frac{T_1}{T_2}.$$

The subscript 1 refers to conditions at the beginning of compression and the subscript 2 to the condition at the end of compression.

106. Cyclic Efficiency (Diagram Factor). The diagram factor is the ratio of the thermal efficiency actually obtained from an engine to the ideal thermal efficiency of that engine;

$$\text{Diagram factor} = \frac{\text{indicated thermal efficiency}}{\text{ideal efficiency}}.$$

In obtaining the ideal thermal efficiency ideal conditions are assumed, namely, no work on the exhaust or intake strokes, no cylinder leakage

and air is taken as the working gas. Thus if an engine has a thermal efficiency of 25 per cent. and the air-card efficiency of this respective engine is 50 per cent., the diagram factor would be 50 per cent. Comparisons of a great number of cards with the air-card, have shown that, in general, the diagram factor decreases with compression.

107. Volumetric Efficiency. The volume of the fuel charge actually drawn into the cylinder of a gasoline engine is less than the displacement of the engine. The ratio of the actual volume of air entering the cylinder, by measurement, to the displacement of the pistons is called the real volumetric efficiency.

The apparent volumetric efficiency is obtained from a low-spring cord as described in detail in an earlier lecture.

If the volumetric efficiency is lowered it means that the charge weight going into the cylinder is low. This will cause a falling off in the pressure at the end of suction or beginning of compression and the mean effective pressure will be reduced. As the mean effective pressure is directly related to the brake-horsepower it is seen that the brake-horsepower will be reduced also.

Heat Distribution

108. Heat Balance. A table showing the distribution of the heat supplied to an engine among the final points of disposal of this heat is termed a heat balance.

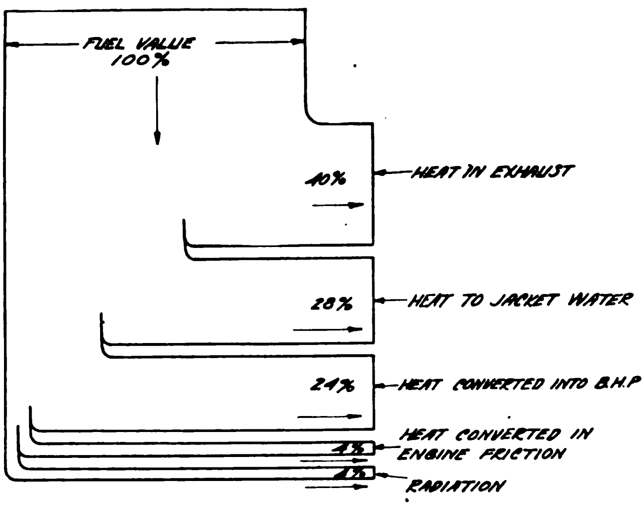

FIG. 90.—Heat distribution.

By measuring the quantity of mixture used in a given time by an engine, the total heat energy of the charge can be calculated, provided the heating value per pound of fuel be known.

The B.t.u. input is considered as 60 per cent. and then by different methods the percentage of heat units going to different sources may be calculated. The following table is an example of a typical heat balance.

TABLE VII.—TYPICAL HEAT BALANCE

1. Heat carried off in exhaust gases	= 40 per cent.
2. Heat given to jacket water	= 28 per cent.
3. Heat available as b.hp.	= 24 per cent.
4. Heat utilized in overcoming engine function	= 4 per cent.
5. Heat lost by radiation	= 4 per cent.

The calculation of the amount of heat lost in the exhaust gases is quite beyond the scope of this course and will not be explained. In practice it is customary to consider all heat not otherwise accounted for as lost to the exhaust.

The heat lost to the jacket water can be calculated by using the formula $H = C(t_2 - t_1)^w$ where C = specific heat of $H_2O - 1$.

$$W = \text{weight of water used.}$$
$$(t_2 - t_1) = \text{temperature rise.}$$
$$H = \text{total heat given to water.}$$

The actual b.hp. developed can be measured by a Prony brake and then converted over into heat units.

The friction horsepower is the difference between the indicated and brake horsepower. By cutting out one cylinder at a time the indicator horsepower of that cylinder will be eliminated but the friction can be determined and converted to heat units by calculation.

There are no accurate methods of measuring the actual amount of heat going into radiation. After deducting the four other quantities, which are measurable, it is customary to consider the heat unaccounted for as radiation.

Mechanics of Engines

109. Introduction. Up to this time the theoretical and physical aspects of the subject of the development of power from the explosive mixture have been considered; thus the manner in which the chemical energy of the fuel is utilized, the peculiar changes accompanying its transformation into mechanical energy, the thermal and pressure changes, and their determination have been dealt with at some length.

It is proposed to briefly study how the heat energy is utilized to do actual work, the forces resulting from the explosion of the gases in the engine cylinder and the important factors affecting engine vibration.

110. Piston Position and Crank Angle. There is a definite relation between the position of the piston and the corresponding crank angle,

which is dependent upon the ratio of the length of the connecting rod to the length of the crank. This ratio,

$$\frac{\text{length of connecting rod}}{\text{length of crank}}$$

is known as n or $1/r$. If the connecting rods were of an infinite length the piston travel could be determined by dropping a perpendicular from the center of the crank pin to the center line, passing through the center of the crankshaft and parallel to the rod. This is represented in Fig. 91.

Assume that the piston is at A, and the crank rotated through an arc of $\propto$ degrees. The new position of the piston will be B, or it will have travelled $\frac{AB}{S} \times 100$ per cent. of its stroke. When the crank has passed through the angle B, the new piston position will correspond to D, or it will have travelled the distance AD.

Because a rod of infinite length is impossible this demonstration is of little value except as a limit to be desired. Fig. 92 represents the graphical method of determining the relation between the piston position and the crank angle. There is a mathematical method but it is too complicated to be considered here.

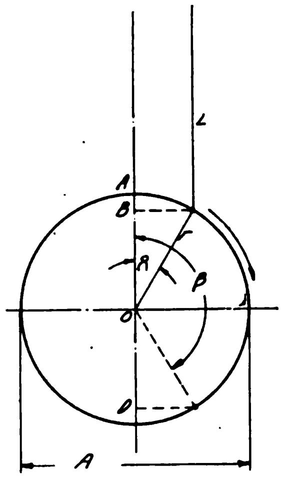

FIG. 91.—Connecting rod of infinite length.

Lay off the crank circle OC, to as large a scale as possible, as this aids in obtaining accurate results. With a radius AA and $B'B$ equal to the length of the connecting rod, and with A' and B' as centers, scribe the arcs A and B, which limit the extremes of the stroke. To find the

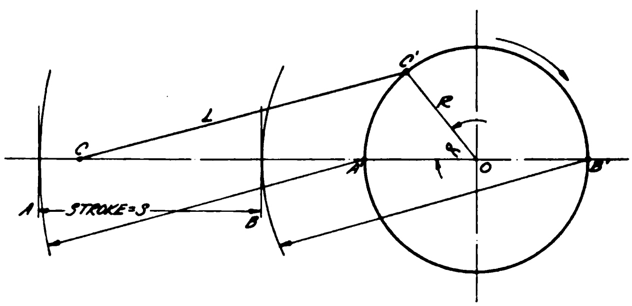

FIG. 92.—Connecting rod of finite length.

piston position when the crank has rotated $\propto$ degrees, scribe an arc between A and B, using a radius of $C'C$, equal in length to the connecting rod and with C' as a center. This point C, is the new piston position. It is determined for any other point in like manner.

If the connecting rod is of finite length, when the crank has rotated 90 degrees past top center, the piston will not have travelled one-half of its stroke but about 55 per cent. or 60 per cent., depending upon the value of n. The greater the value, the nearer the piston position approaches 50 per cent. Another fact to consider is that, for equal crank angles on the inner and outer strokes, the relative piston position is not equal. Refer to Fig. 93, which represents a two cylinder engine with crank at 180 degrees. When the crank has rotated 30 degrees past the top and bottom centers respectively, the piston A has travelled down 8.8 per cent. of its stroke, while the piston B has gone up only 4.3 per cent. of its stroke. These values vary with a variation in the connecting-rod crank ratio.

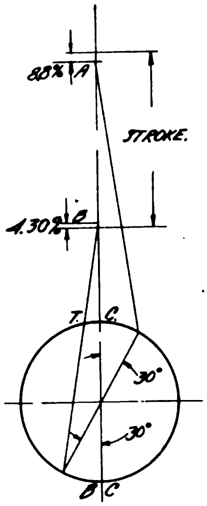

FIG. 93.—Relation of piston travel at top and bottom of stroke.

It is often desired to time a motor by the piston position, and the available valve timing is given in crank angles or vice versa. Tables VIII and IX, are complied for such use. The three values of n given, cover the range of airplane practice. If it is desired to find the piston position corresponding to 10 degrees past top center for an engine having a 12 in. connecting rod and a 4 in. crank, first determine the value of n which is $1/r$ or, $\frac{12}{4}$ and equals 3. Now refer to Table IX under the column headed crank angle. Follow down this column to 10 degrees and across to the

TABLE VIII.—PISTON POSITION VS. CRANK ANGLE

No. of strokes.	$n = 3$	$n = 3.5$	$n = 4$
0	0	0	0
2.5	15.0	16.2	16.3
5	22.3	23.0	23.2
10	32.2	33.1	33.3
20	46.8	47.5	48.1
30	58.2	59.6	61.0
40	69.2	71.0	72.0
50	80.6	82.1	83.2
60	91.7	93.5	95.0
70	103.2	105.4	107.0
80	117.8	119.8	121.0
90	136.0	137.8	138.2
95	148.1	150.5	151.2
97.5	158.0	159.8	160.2
100	180.0	180.0	180.0

TABLE IX.—PER CENT. OF STROKE

Crank angle	$n = 3$	$n = 3.5$	$n = 4$
0	0	0	0
10	1.3	1.7	1.2
20	4.2	3.9	3.8
30	8.8	8.5	8.3
40	15.0	14.4	14.1
50	22.8	22.0	21.5
60	31.5	30.5	29.5
70	40.5	39.1	38.2
80	49.4	48.0	47.0
90	58.5	57.0	56.0
100	67.0	65.2	64.0
110	74.8	73.6	72.0
120	81.2	80.2	79.5
130	87.3	86.2	85.5
140	91.3	91.0	90.8
150	95.7	94.6	95.1
160	98.0	97.5	97.4
170	99.5	99.0	99.3
180	100	100	100

right, under the column headed $n = 3$. Here the relative piston position is 1.3 per cent. of the stroke, which means that the piston has travelled down 0.013×8 or 0.104 inches. For any other crank angle or value of n, the tables may be interpreted fairly accurately or as accurately as measurements can be taken. Table VIII is inserted to facilitate determining the crank angle corresponding to a given piston position.

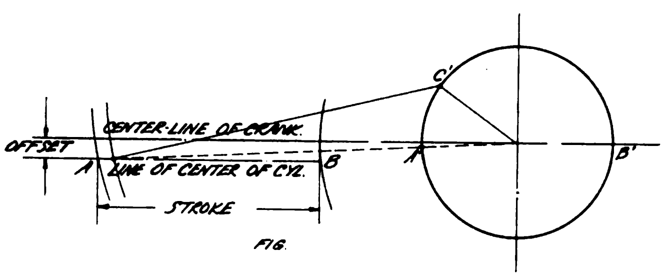

FIG. 94.—Offset cylinders.

If the cylinders are offset the graphical method for determining the relative piston and crank position is the same as just described, except that the arcs are struck off on the center line of the piston travel which is parallel to, but separated from the center line of the crank. See Fig. 94.

111. Piston Velocity. Piston velocity vs. crank angles. As the piston position, relative to the crank angle, is dependent upon the connecting rod-crank ratio, so is the piston velocity relative to the crank

velocity and crank angle dependent upon the vaue of n or $1/r$. The crank velocity is nearly constant; so nearly so, that we will assume that it is constant. But the pistons velocity is zero at either end of the stroke and reaches a maximum somewhere near the middle. If the rod were of infinite length the piston velocity would be at a maximum at the middle of its stroke and its motion would be a simple harmonic one. With the value of $1/r$ or n, as used in airplane engines, the maximum piston velocity

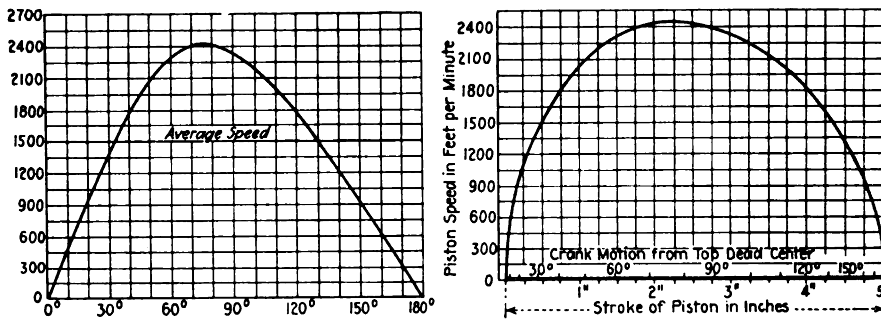

FIG. 95.—Piston speed plotted against crank motion and piston position.

occurs when the crank has travelled from 70 to 80 degrees past top center, or when the piston has travelled from 30 to 40 per cent. of its stroke. Its velocity is at a maximum when the crank and connecting rod are at right angles. Fig. 95 shows a piston velocity-crank angle curve and also a piston velocity-piston travel curve.

Either the graphical or mathematical method may be used for determining the piston velocity. The graphical method will be considered first and is shown in Fig. 96.

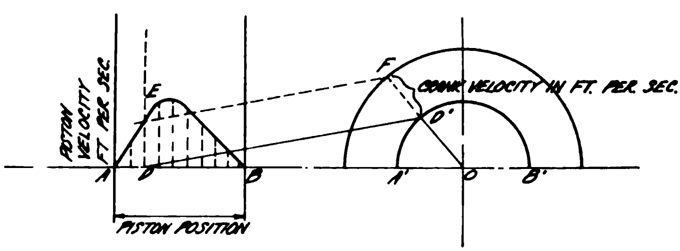

FIG. 96.—Graphical method determining piston velocity.

Lay off the circle OD' with a radius equal to the crank throw; locate the extremes of the piston travel with a radius $A'A$, $B'B$ being equal to the connecting rod length $d'd$. Draw the circle Of making d' equal the crank velocity. With the crank in any position d', locate the corresponding piston position d, and erect a perpendicular. Now draw a line from f parallel to $d'd$ until it cuts the perpendicular at e. This distance

ed, is the piston velocity at that point. Continue this, using various crank angles until sufficient points are obtained, through which draw a curve, as shown in Fig. 96.

To obtain the piston velocity mathematically for any piston position, substitute known values in the formula $V = .00874N^2rCv$. Where

V = velocity of piston in feet per second.
N = revolutions per minute of crankshaft.
r = throw of crank in inches = $\frac{\text{stroke}}{2}$
C^v = constant obtained from Table X.
n = $1/r$ ratio of connecting rod length to crank length.

Example. Determine the piston's velocity when it has completed 30 per cent. of its stroke from the head end, if the connecting rod is 12 in. long, the crank throw 3 in. and r.p.m. 1500.

$$n = 1/r = 12/3 = 4.$$

To determine for 30 per cent. of the stroke with an n value of 4, refer to Table X and under the column marked "Per cent of stroke," find a value of 30. Then follow across to the right and pick out the desired value under the column marked "n = 4," which is .925. Then substitute in the formula:

$$\begin{aligned} V &= .00874\ N^2rCv \\ &= .00874 \times 1500^2 \times 3 \times .925 \\ &= 363\ \textit{ft. per sec. piston velocity.} \end{aligned}$$

TABLE X.—Cv EQUALS VELOCITY

Per cent. of stroke	$n = 3.0$	$n = 3.5$	$n = 4.0$
0	0	0	0
5	0.505	0.480	0.430
10	0.685	0.675	0.570
20	0.890	0.870	0.780
30	1.000	0.970	0.925
40	1.050	1.030	1.005
50	1.040	1.030	1.028
60	0.985	0.980	1.005
70	0.885	0.900	0.930
80	0.745	0.770	0.820
90	0.525	0.560	0.620
95	0.370	0.380	0.530
100	0	0	0

TABLE XI.—Ca EQUALS ACCELERATION

$n = 3.0$	$n = 3.5$	$n = 4.0$
1.33	1.29	1.25
1.17	1.13	1.10
1.00	0.980	0.95
0.69	0.670	0.65
0.38	0.370	0.36
0.09	0.100	0.11
−0.16	−0.140	−0.12
−0.37	−0.355	−0.33
−0.54	−0.520	−0.50
−0.66	−0.630	−0.630
−0.70	−0.700	−0.71
−0.69	−0.715	−0.74
−0.667	−0.714	−0.75

112. Piston Acceleration. The piston is constantly changing its velocity or rate of travel. At the beginning of the stroke its velocity is zero, then it increases to a maximum just before it reaches the midpoint of its stroke. From here on its velocity decreases until it reaches zero at the crank end. The rate of change of velocity or the acceleration varies with the piston position revolutions per minute, crank radius and the value of $1/r$.

For the graphical solution of the piston acceleration reference is made to Judges "High Speed Internal Combustion Engines." Only the mathematical method will be considered here. To obtain the piston acceleration for any position of the stroke substitute in the formula $A = .0009125\ N^2rCa$.

Where

A = piston acceleration in feet per second.
N = revolutions per minute of crankshaft.
r = throw of crank in inches $= \frac{\text{stroke}}{2}$.
Ca = constant obtained from Table XI, depending upon the piston position and the value of n.
$n = 1/r$ = ratio of connecting rod length to crank length.

For the value of Ca, refer to Table XI. The method is the same as for obtaining the piston velocity, except that Table XI is used instead of Table X. The acceleration is always at a maximum at the head end of the stroke, reaches zero somewhere near the middle and increases in value toward the crank end. See Fig. 97.

113. Inertia Forces. Because the piston is constantly accelerating, an inertia force is exerted of varying magnitudes. At all times the inertia

force is opposite the acceleration. Thus, when the piston leaves the head end of the stroke it is accelerating positively and the inertia force is considered negative because the piston is requiring work to accelerate it. As the position velocity starts to decrease, acceleration negative, the inertia force of the piston is considered positive because the piston is giving up work. A piston inertia force curve will show the same shape as the acceleration curve, shown in Fig. 97, but will be of different magnitude. The inertia force can be obtained from the formula $F = MA$ where F is the inertia force, M the mass of the body and A, its acceleration. To facilitate computation, a special formula has been devised which will give the inertia force directly without making a separate computation for the acceleration.

Formula: $F = .0000283\ WN^2rCa$

Where F = Inertia force of reciprocating parts in pounds.

W = Weight of recripocating parts in pounds.

N = Revolutions per minute of crankshaft.

r = Throw of crankshaft in inches $= \frac{\text{stroke}}{2}$.

Ca = Constant obtained from table IV, depending upon the piston position and the value of r.

$n = 1/r$ = ratio of connecting rod length to crank length.

An important fact to be pointed out is that the sum of the negative work done during acceleration is equal to the sum of the positive work done during retardation. That is, there is no work lost accelerating and retarding the pistons in an engine. The ony loss comes from the bearing friction which results, but that is very slight. This is to be emphasized to point out that a light piston has no advantages over a heavy piston from this viewpoint. The big advantages of a light piston is in the reduction of vibration which results from its use. To further emphasize this, refer to Fig. 97. The shaded area representing the positive work is equal to the shaded area representing the negative work. The inertia force is zero at point A and corresponds to about 45 per cent. of the stroke. It also represents the point where the acceleration is zero and where the piston velocity is a maximum, which occurs when the crank and the connecting rod are at right angles. The inertia force B at the head end is always the maximum, being greater than c at the crank end. So far no mention has been made of any part except the piston, as having an inertia force. There are other parts to consider but they are not as important. The valves create

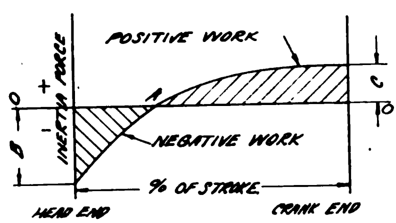

FIG 97.—Inertia diagram.

inertia difficulty. If they are too heavy excessively heavy springs are necessary to close them on time.

114. Crank Velocity. The velocity of the crankshaft is of importance because it is one of the factors effecting the centrifugal force of the crankpin and assembly. The linear velocity of the center of the crankpin can be obtained from the formula $V = \frac{2\pi rN}{60}$, where V is the velocity in feet per second, r is the crank throw in feet and N the revolution per minute. $2\pi rN$ must be divided by 60 to reduce the result to feet per second.

115. Centrifugal Forces. The part which presents the greatest difficulty because of centrifugal forces is the crank and lower end of the connecting rod. The value of the force can be determined from the formula $F = \frac{WV^2}{gr}$, where F is the centrifugal force in pounds, W is the weight in pounds of the rotating body, V is the linear velocity of the body in feet per second, g is the acceleration due to gravity and equal to 32.2 and r is the distance in feet from the body to the center of rotation.

Example. Determine the centrifugal force exerted by a propeller rotating at 1,500 r.p.m. if the unbalanced portion weighs one ounce and is located four feet from the center of the hub.

The velocity of the unbalanced body is $V = \frac{2\pi rN}{60} = \frac{2\pi \times 4 \times 1{,}500}{60}$ $= 628$ ft per sec.

The centrifugal force is $F = \frac{WV^2}{gr} = \frac{1 \times 628 \times 628}{16 \times 32.2 \times 4} = 191$ lb.

116. Resolution of Forces. Any single force can be resolved into component forces, that is, forces which may replace and produce the same effects as the single force. Thus the single force A, Fig. 98, can be resolved into two forces B and C, which will equalize it. To do this it is necessary to construct a force polygon as shown. First it must be decided through what plane one of the component forces is to act. Then the lines B and C are from the origin of the force A.

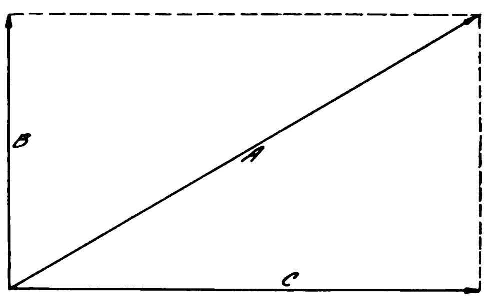

FIG. 98.—Component forces.

The extent of B and C is determined by dropping a perpendicular from the extreme of the single force to the lines B and C. A, B and C will each represent a force, the two forces B and C being the components of the force A and of sufficient magnitude and proper direction to replace it and produce an equivalent effect.

To state the reverse of the foregoing the two forces can be combined into a resultant force; that is a single force which will be equivalent and will produce the same effects as the two forces. The process is the re-

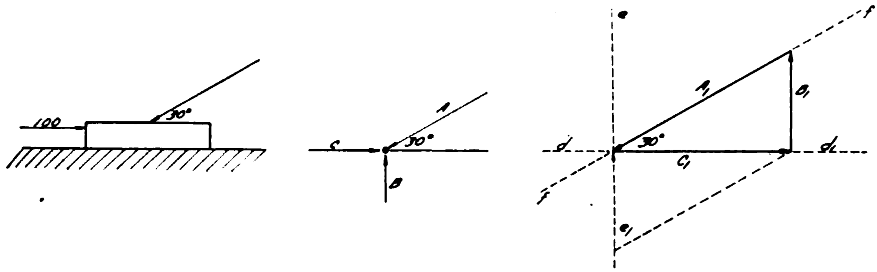

FIG. 99.—Resolution of forces.

verse of the above. In this case force *A* is the resultant of the two forces *B* and *C*.

An example of the resolution of forces will help to fix the idea in the mind. The first thing to do is to draw a "point force diagram," that is, locate a point and apply to that point all the forces which are acting there.

A box is pulled across the floor by a force of 100 lb. What force will be necessary to move the box if the force acts at 30 degrees, as shown in Fig. 99.

The point force diagram shows three forces; *A*, the force acting at 30 degrees, *B*, the reaction of the floor against the box and *C* the resistance which the box offers to motion, that is, the horizontal force necessary to move it. Now to determine the value of the forces, draw the center lines *dd′* and *ee′*. Lay off *C′* equal to *C* and to suitable scale. Draw a dotted line *ff′* through the locus at an angle of 30 degrees to the horizontal and erect a perpendicular from the extreme of the line *C*, until it cuts *ff*. This will form a line *A′* which is equal to the force necessary to move the box when applied at an angle of 30 degrees. To get the direction in which the forces are acting, place the arrow on *C′* in the proper position and apply the others so that they will follow each other. The value of *C* is 115 lb. Forces may also be

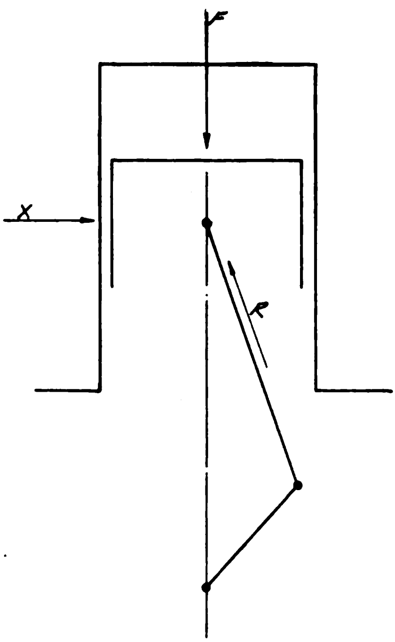

FIG. 100.—Wristpin forces.

determined by using trigonometric functions but it requires the use of mathematics and is, therefore, not advisable here.

When the gas force F, Fig. 100, acts on the piston, it creates a side thrust x and a force along the connecting rod R. It is easier to compute these by the mathematical method than by the graphical method, provided the accompanying tables be used.

The side thrust against the cylinder wall is dependent upon the force on the piston, the value of $1/r$ and the crank angle. It can be determined from the formula $X = F \times C_x$, where X is the side thrust in pounds, F the instantaneous gas force in pounds per square inch and C_x, a constant depending upon the value of $1/r$ or n and the crank angle which can be obtained from Table XII.

Table XII.—Data for Determining the Forces Due to Connecting Rod Angularity

Crank angle	$n = 3.0$			$n = 3.5$			$n = 4.0$		
	C_x	C_r	C_t	C_x	C_r	C_t	C_x	C_r	C_t
0 360	0	1.000	0	0	1.000	0	0	1.000	0
10 350	0.058	1.002	0.231	0.050	1.001	0.222	0.043	1.001	0.216
20 340	0.114	1.007	0.449	0.098	1.005	0.436	0.086	1.003	0.422
30 330	0.167	1.015	0.648	0.143	1.011	0.624	0.125	1.008	0.608
40 320	0.214	1.024	0.810	0.184	1.018	0.786	0.161	1.013	0.769
50 310	0.256	1.035	0.936	0.219	1.025	0.910	0.142	1.019	0.893
60 300	0.289	1.044	1.015	0.248	1.032	0.994	0.217	1.024	0.976
70 290	0.319	1.054	1.052	0.268	1.038	1.035	0.235	1.029	1.021
80 280	0.328	1.058	1.042	0.281	1.042	1.035	0.246	1.031	1.027
90 270	0.333	1.060	1.000	0.286	1.044	1.000	0.250	1.032	1.000
100 260	0.328	1.058	0.925	0.281	1.042	0.935	0.246	1.031	0.942
110 250	0.313	1.054	0.826	0.268	1.038	0.845	0.235	1.029	0.856
120 240	0.289	1.044	0.714	0.248	1.032	0.738	0.217	1.024	0.755
130 230	0.256	1.035	0.595	0.219	1.025	0.621	0.192	1.019	0.649
140 220	0.214	1.024	0.475	0.184	1.018	0.498	0.161	1.013	0.517
150 210	0.167	1.015	0.353	0.143	1.011	0.376	0.125	1.008	0.391
160 200	0.114	1.007	0.235	0.098	1.006	0.248	0.086	1.003	0.263
170 190	0.058	1.002	0.116	0.050	1.001	0.125	0.043	1.001	0.131
180 180	0	1.000	0	0	1.000	0	0	1.000	0

Example. Determine the piston side-thrust for a crank angle of 30 degrees, if the instantaneous gas force is 1,000 lb., the connecting rod 12 in. long and the crank throw 3 in.

Refer to Table XII, to the column marked "crank angle." Follow across from "30" to the section marked "$n = 3.5$" because $1/r = 12/3 = 4$. Here stop under the column marked "C_x," where the desired constant is found to be .143. Substitute this in the formula $X = F \times C_x$ and the result is 143 lb. side thrust.

$$X = 1{,}000 \times .143 = 143 \text{ lb. side thrust.}$$

The force along the connecting rod is obtained in the same way, except that the constant is obtained under a column marked "*Cr*". In the three formulas given in Table XII, C represents a constant and the subscripts x, r and t denote the ownership. Thus C_x is the constant for side thrust, C_r the constant for determining the force along the connecting rod and C_t, the constant for use in the torque formula.

α = crank angle
β = rod angle.

FORMULAS

$x \times F = C_x$

$R = F \times C_r$

$T = F \times C_t \times \dfrac{r}{12}$

F = total force on piston in pounds
= area of piston square inches $\times$ instantaneous.
pressure in pounds per square inch.
R = force along rod in pounds.
X = side thrust of piston in pounds.
T = torque in pound feet.
l = length of connecting rod in inches.
r = throw of crank in inches
n = $1/r$

At all times the force along the connecting rod is equal to or greater than the force exerted on the piston. In Fig. 99, 100 lb. is the resistance which the box offers to motion in a plane parallel to the floor, but it was necessary to apply 115 lb. at an angle of 30 degrees to move it. Now, to refer to the engine, the piston force may be 2,000 lb. but in order to equal it at an angle of β degrees a greater force must be applied.

117. Gas Forces. The energy, which is eventually produced as useful work at the crankshaft, and which also creates the internal stresses in the engine, originate from the burning of the fuel in the cylinder. The fuel is ignited in the cylinder and exerts a pressure on the piston. This pressure is at a maximum when the piston is near the head end and decreases as it nears the crank end. This varying pressure is transmitted from the piston by the connecting rod to the crankpin and causes the crankshaft to rotate. The connecting rod serves as a medium by which the reciprocating motion of the piston is transformed to rotating motion at the crankshaft. Due to the angularity of the connecting rod a side thrust against the cylinder wall is exerted by the piston. One of the factors governing the magnitude of the piston side-thrust face on the crankpin and torque is the force which is exerted on the piston. Every change in piston position means a change in the force exerted on the piston and therefore it is necessary to consider not the average force exerted on the piston by the cases of which the mean effective pressure is a factor, but the instantaneous gas force for each position of the piston. This instantaneous gas force for any given piston position is determined from the instantaneous gas pressure for that position and the area of

the piston. Thus, if the instantaneous gas pressure is 200 lb. per sq. in. when the piston has travelled 20 per cent. of its stroke and the piston area is 20 sq. in., the instantaneous gas force is 200 × 20 or 4,000 lb. To obtain the instantaneous gas pressure it is necessary to obtain an indicator diagram for the cylinder under consideration. If an actual card is not available an imaginary one can be drawn and the results obtained with approximate the correct ones. In order to facilitate interpretation, the card should have the four piston strokes plotted separately instead of in the usual manner. Also plot the ordinate as total force rather than pressure. Fig. 101 represents a diagram so drawn and is the ideal card for the Liberty engine.

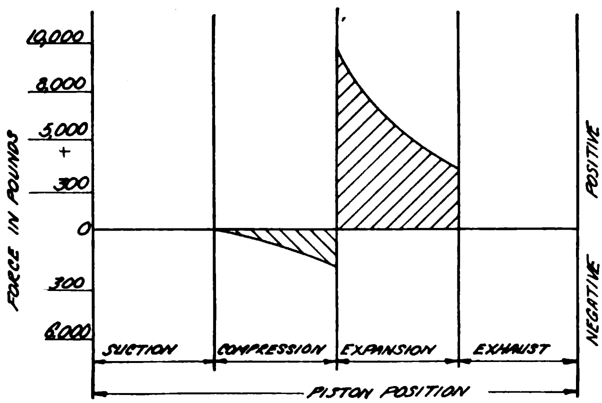

Fig. 101.—Ideal ignition card.

The ordinate is plotted as total force in pounds, which is the pressure in pounds per square inch times the piston area. This card will be neglected for a time but it will be used later to find the instantaneous turning effort or torque. The diagram in Fig. 101 is plotted showing zero work done during intake and exhaust, which is theoretically correct. Actually however, some work will be done in each case.

118. Combined Gas and Inertia Forces. Besides the gas forces acting on the piston there is the inertia force which at high rotative speeds, may equal or exceed the gas forces. It is therefore necessary in determining the torque developed by an engine to consider both forces and obtain a resultant force for substitution in the torque formula. This resultant force is determined by obtaining a combined gas and inertia force diagram, as shown in Fig. 102. The ideal indicator diagram is laid off as previously explained and to the same scale the inertia diagram for each stroke is drawn. Then the two are combined by addition. Thus, at the end of the compression stroke there is a negative gas force of 2,000 lb. and at the same time a positive inertia force of the same amount.

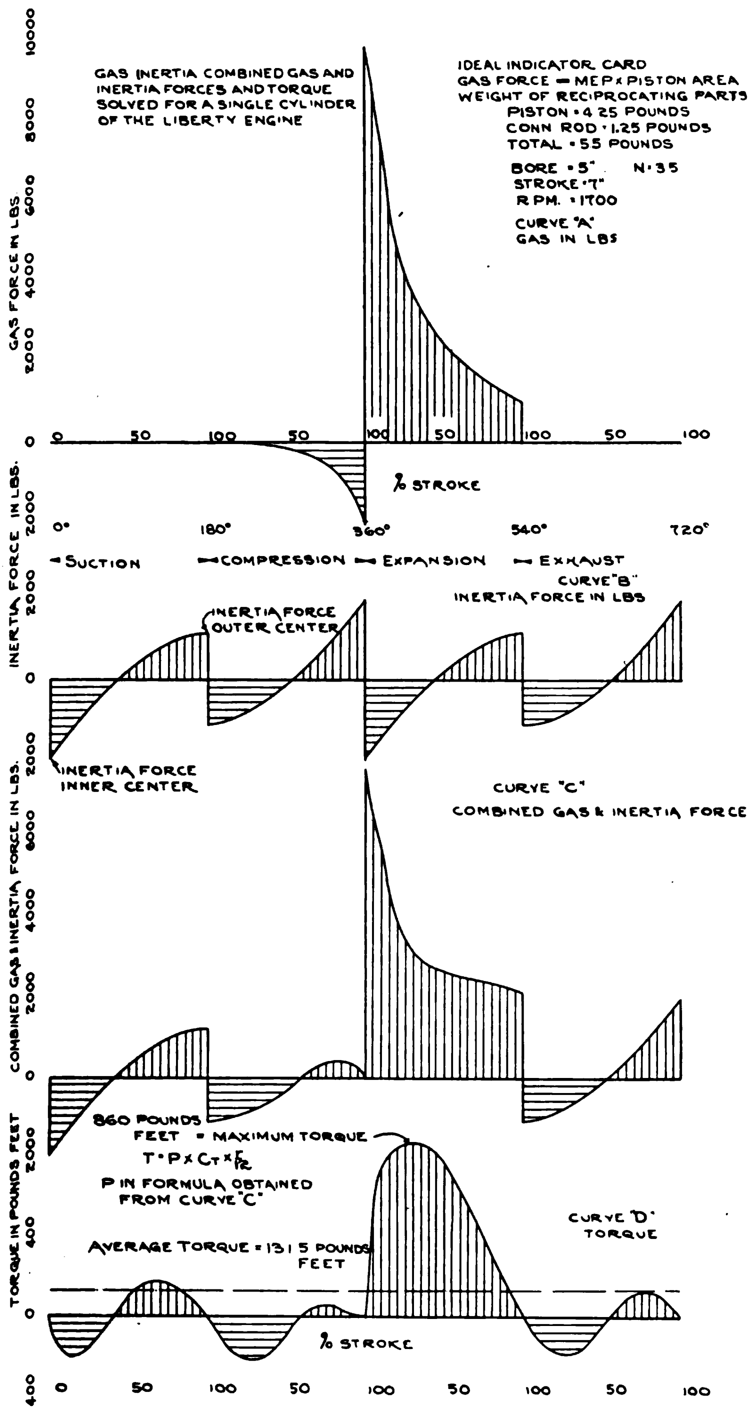

FIG. 102.—Diagram showing combined gas and inertia forces and resultant turning effort.

The two combined give a net force of zero. For other points the force may be either positive or negative.

119. Torque, which has been discussed at length earlier, is the twisting effort or ability to cause rotation. The torque is constantly varying in magnitude and direction and therefore the easiest way to represent it is by a curve. The torque is dependent upon the force exerted on the crankpin, the length of the crank and the crank angle. It can be computed from the formula $T = F \times C_t \times r/12$, where T is the torque in pound-feet, F the instantaneous force exerted on the piston and r the throw of the crank in inches. The constant C_t is a combination of the constant C_r from which the force on the crankpin is obtained, and another constant. The torque is the product of the force on the crankpin perpendicular to the crank and the length of the crank. Since the connecting rod and the crank are perpendicular to each other only once per stroke, it is necessary to determine either a resultant force or a resultant lever arm, as shown in Figs. 67 and 68. The first method is used and the constant C corrects for this change in angularity. From the combined gas and inertia force curve, obtain values of the force for substituting in the torque formula, $T = F \times C_r = r/12$. Compute the torque for a sufficient

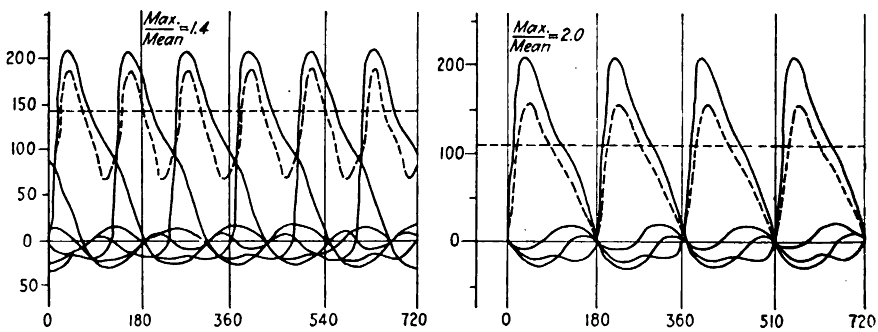

Fig. 103.—Four and six cylinder torque diagram.

number of points to obtain a good curve. It will be seen that the torque is zero at the start and end of each stroke and fluctuates in magnitude and direction. The maximum torque is obtained at 30 per cent. of the power stroke. The varying torque has been reduced to an average which shows 131.5 lb.-ft. If the engine were a single-cylinder machine it would be necessary to use a heavy flywheel in order to distribute the torque over the four strokes. A 2-cylinder engine will have twice as many power impulses as a single-cylinder engine. Thus, the power impulses are distributed over a greater range and a smaller balance wheel can be used.

By referring to Fig. 103, it can be seen how the torque increases in constancy by the addition of cylinders.

Engine Balance

120. Reciprocating Parts. Those parts that move back and forth are called reciprocating parts.

Piston assembly. When an explosion takes place a certain force is required to start the piston in the cylinder. It takes the same amount of energy to stop the piston at the end of the stroke. Under the piston assembly consider all reciprocating parts attached to it; such as the piston itself, wristpin, pin retainer, piston rings, screws and the upper part of the connecting rod. The piston and everything attached to it, except the connecting rod, truly reciprocate when in motion. In the case of the connecting rod, there is a combination of rotating and reciprocating motion. However, the upper part of the rod is always considered reciprocating.

The method of determining which portion of the connecting-rod is reciprocating weight, has been covered in a previous lecture.

FIG. 104.—Balanced forces.

Inertia diagram. The inertia diagram shows the pounds force plotted against the per cent. stroke, or crank angle. Wih the aid of the compiled tables, and the necessary data at hand, it is possible to compute the inertia force for any per cent. of the stroke. See Fig. 36. Negative work is done in getting the piston started, and the piston works, or gives up the same amount of energy that it received, in coming to rest. Therefore, the work below the line is always equal to the work above the line.

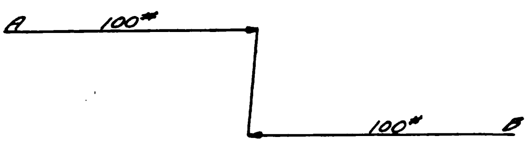

FIG. 105.—Unbalanced forces.

Balance in Relation to Number and Arrangement of Cylinder. If two forces are equal, and acting in opposite directions in the same straight line, the forces are said to be balanced. That is, if A and B in Fig. 104, were both equal to 100 lb. and were acting in the same straight line as, $X - X$, there would be no resulting motion, and the forces would be balanced. If these same forces were not in the same straight line, but were parallel, there would be no balance. The action of the two forces would have a tendency to rotate the body upon which they were acting.

Here A and B in Fig. 105 are equal, and parallel, but they are not in the

same straight line. Therefore there would be a tendency to rotate about the point *O*. In the case of the inertia forces of an engine, if a force acting is equal and opposite to No. 2, at same time No. 1 is acting, a perfect balance is obtained, see Fig. 106. In a single cylinder engine No. 1 is the only force acting, and excessive vibration takes place, due to the unequal inertia forces.

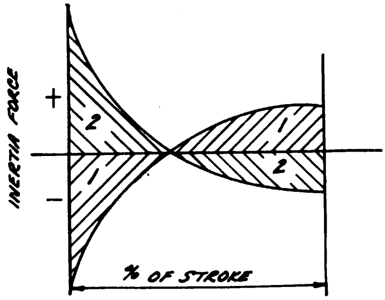

FIG. 106.—Inertia diagram two-cylinder opposed engine.

Two Cylinders in Line, Crank at 360 Degrees. In a 2-cylinder engine with the crankthrows at 360 degrees the torque impulses occur at equal intervals but the inertia forces are excessive. In plotting the inertia diagram for each cylinder the separate diagram for *A* is plotted, and then the one for *B* in Fig. 107. The two must be combined. Excessive inertia forces result as shown in *C*. The torque of a 4-cylinder engine is 100 per cent. more uniform than that of a two, but the unbalanced inertia forces are equal. The 4-cylinder is equivalent to a double 2-cylinder engine, with cranks at 180 degrees coupled.

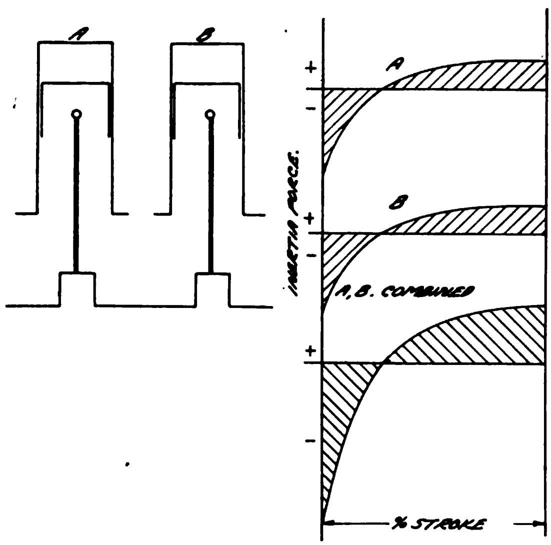

FIG. 107.—Inertia force diagram two cylinders-in-line. Cranks at 360 degrees.

A 2-cylinder engine, with the cranks set at 180 degrees, furnishes power impulses which do not occur equally spaced. During 36 degrees there will be two power strokes. Then for the next 360 degrees there will be no power impulses. The torque curve is shown in Fig. 109. If constant torque is desired this type fails. It is the balance characteristics

which keep it in favor. Most 2-cylinder marine motors are constructed in this way.

Consider the inertia diagram from such an engine, Fig. 108. Curve B is for cylinder B, and curve A for cylinder A. When A is leaving the

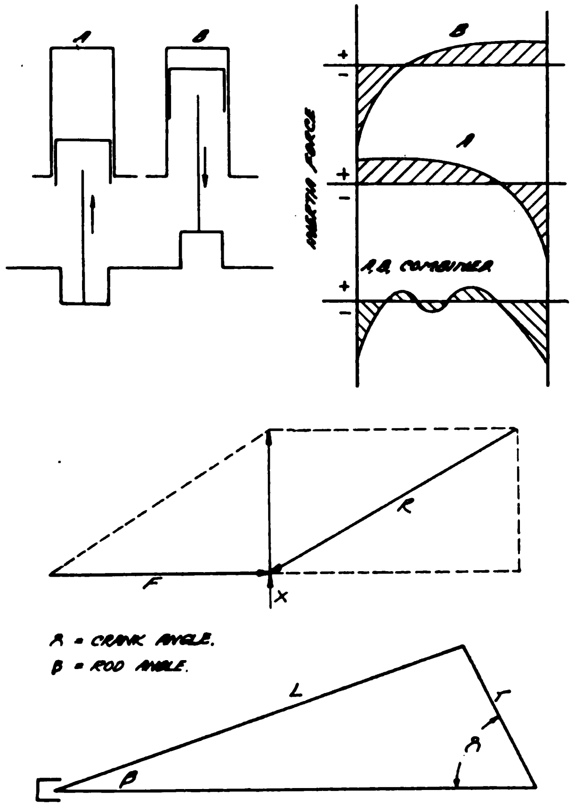

FIG. 108.—Inertia diagram two cylinders-in-line. Cranks at 180 degrees.

crank end of the stroke it requires an upward force to start it. At the same time B commences motion and a downward force is necessary to start it. These forces are in opposite directions, and if of equal magni-

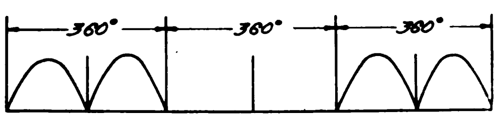

FIG. 109.—Uneven impulse spacing, for two cylinders-in-line. Cranks at 180 degrees.

tude are balanced. But the inertia force at the head end is always greater than at the crank end. Consequently the forces are out of balance and are reduced in value. Curve D is the resultant.

Had this engine been constructed with cranks at 360 degrees, even torque spacing would have resulted. The inertia force of one cylinder would have added to that of the other, instead of reducing it, as it did with the cranks at 180 degrees.

Therefore, with heavy duty engines it is desirable to have the cranks at 180 degrees. Balance weights may be added but they present many difficulties.

The 2-cylinder opposed engine, with throws at 180 degrees, has the cylinders placed upon opposite sides of the crankshaft. This is shown

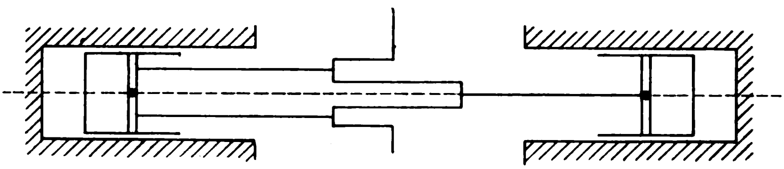

FIG. 110.—Two-cylinder opposed engine cylinder-in-line.

in Fig. 110. The firing strokes are evenly spaced, thus yielding a torque of regular character.

By arranging the cylinders so that the two lines of stroke coincide, the motions of the two pistons balance each other, and no rocking movements occur. This can be accomplished in practice by employing a pair of connecting rods for one cylinder symmetrically placed upon either side of the other, the balance, in fact, is as nearly perfect as is possible in any type of engine. The only unbalanced factors that occur are the variation in torque due to piston inertia, and to the explosion impulse. With this type of engine, owing to its excellent balance, rotative speeds of over 5,000 r.p.m. have been attained.

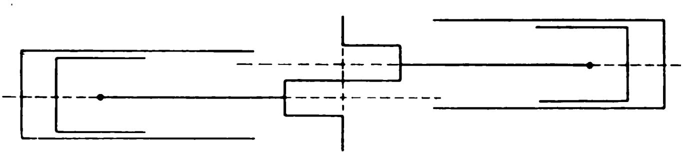

FIG. 111.—Two-cylinder opposed engine.

It is often impossible to arrange the cylinders coaxially for manufacturing reasons. The axis of each cylinder is situated opposite to its own crank, the two axis being out of line as shown by Figs. 111 and 112. In this type of engine it is seen that the forces are equal and in opposite directions. The power impulses are evenly spaced and the inertia forces are balanced, except for the inertia couples. These will be explained later.

In speaking of V-type engines, it may be said that the greater the angle between the cylinders, the nearer they come to approaching the balance

of the opposed type of engine; the smaller the angle, the more nearly they approach the balance of an engine whose cylinders are vertical, and in line.

When two parallel forces are acting in opposite directions, but not

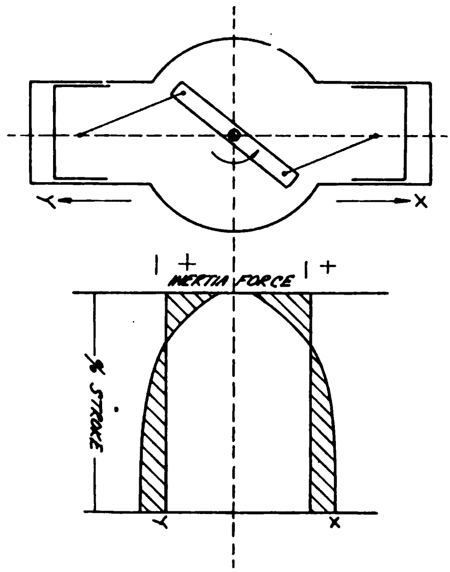

FIG. 112.—Two-cylinder opposed engine, inertia diagram.

in the same plane and tend to cause rotation normal to the natural plane of rotation of the shaft, the condition is known as a force couple.

Thus the shaft in Fig. 113 is rotating about AB as its center, in the direction of the arrow C. The forces D and F are acting in opposite

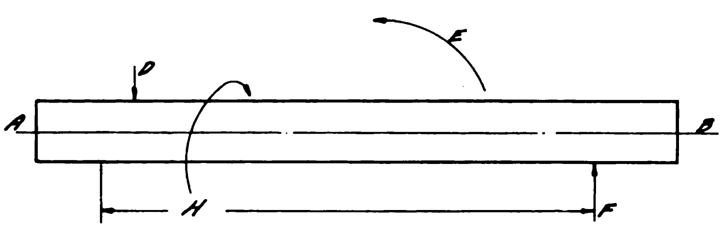

FIG. 113.—Force couple.

directions and are trying to cause rotation in the direction of the arrow E. Thus, D and F times the distance between them comprises the force couple, provided D and F are equal.

If the couple is due to inertia forces, it is known as an inertia couple. If due to centrifugal forces it is known as a centrifugal couple.

In Fig. 114, the torque is equal to 100 lb. multiplied by the perpendicular distance e between the two forces. This would be the same as 100 lb. times 2. If the distance x was equal to 3 ft. the resulting torque

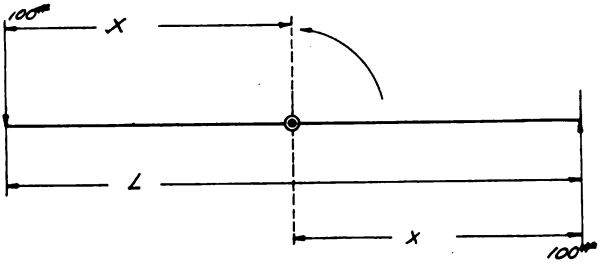

Fig. 114.—Torque due to force couple.

would be $100 \times (2 \times 3) = 600$ ft.-lb. These forces would tend to cause a rotation in the direction indicated by the curved arrow Y. There is equal torque exerted by a force couple. In order to overcome a force couple and produce equal balance, the forces must be brought very close together by shortening the perpendicular distance. As this distance decreases the couple decreases, provided the exterior forces do not change their value. By decreasing this perpendicular distance to zero the result would be two opposite forces acting in the same straight line and thus equilibrium would be maintained. By bringing the crank-throws more closely together, as shown by Fig. 115 the inertia couple may be reduced.

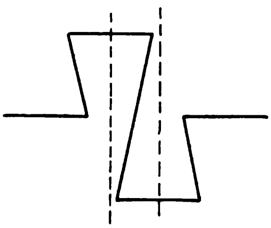

Fig. 115.—Two-cylinder crankshaft.

The 4-cylinder crank is balanced from the couple standpoint. The tendency to rotate, caused by one set of cranks, is overcome by the other set.

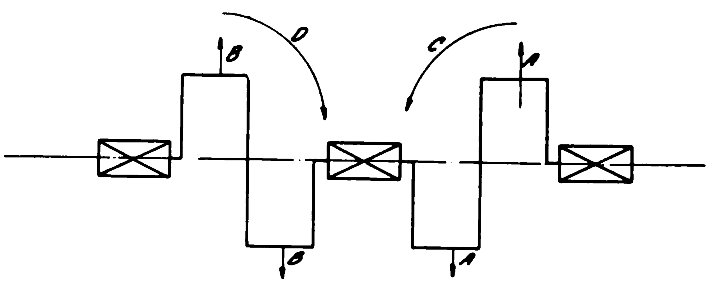

Fig. 116.—Method of reducing inertia couple.

In this case the inertia couple A-A tends to turn the whole shaft in the direction indicated by the curved arrow, C, while at the same time the inertia couple B-B tries to turn the shaft in the opposite direction, in-

dicated by the arrow *D*. The force couples therefore tend to balance each other.

It is possible, in many cases, to reduce the inertia forces in the opposite direction. This is particularly true with steam locomotives. The heavy reciprocating parts which include the piston, piston rod, crosshead and other minor parts create inertia couples of great magnitude. This causes the locomotive to lurch from side to side on the track. In order to reduce these forces, balance weights are added to create forces acting in the opposite direction to the inertia forces. Thus, when the piston is at the head end and exerting its maximum inertia force, the balance weight is exerting an opposite force, which reduces the inertia force. The addition of this balance weight reduces the lurching action, but it has a detrimental effect.

The balance weight causes "rail pounding," which is the result of the tendency of the balance weight to alternately lift from and bear heavily against, the track. It is, therefore, necessary to select a balance weight which will reduce the inertia couple, as far as possible, but not great enough to cause excessive "rail pounding." The same principle has been applied to high-speed internal-combustion engines.

121. Rotating Parts. *Crankshaft.* Rotating parts, such as the crankshaft, will cause vibrations. The magnitude of this vibration depends upon the degree of unbalance. They are as detrimental as inertia vibrations, but may be overcome more easily. These forces set up by rotating parts are known as centrifugal forces. They vary as the square of the speed. Fig. 117 represents a weight of *W* pounds, rotating about a point at a radius of *V* feet. Then the centrifugal force *F* which pulls diametrically from the center $= \frac{WV^2}{GR}$

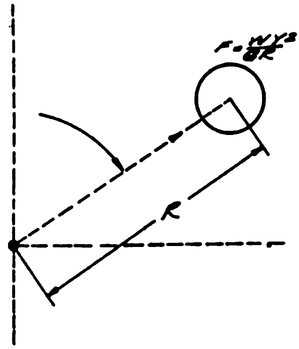

Fig. 117.—Computing centrifugal force.

Formula:

$$F = \frac{WV^2}{GV}$$

Notation.

F = Force in pounds. G = 32.2.

W = Weight of mass in pounds. R = radius in feet.

V = Linear Velocity of mass in feet per second $= \frac{2\pi rN}{60}$

As previously mentioned the centrifugal force constantly varies in direction, and always pulls straight from the center of rotation. For an example, consider a single-cylinder engine as shown in Fig. 118. The centrifugal force will pull at A, tending to lift the motor; then at B, tending to pull the motor to the right. This continues and pulls the motor in every direction, normal to the axis of rotation.

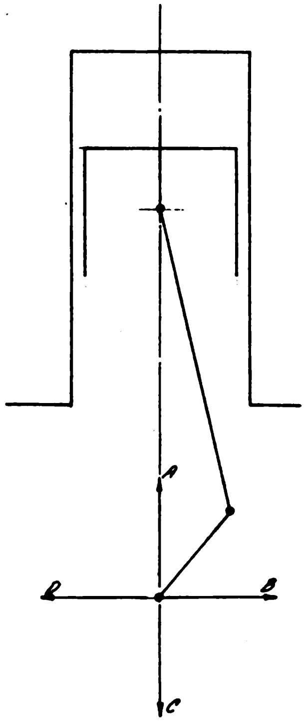

FIG. 118.—Centrifugal force of crankshaft.

Assuming the crankpin and rotating part of connecting rod to weigh 5 lb. and to rotate at 1,000 r.p.m. at a radius of 6 in., the centrifugal force will be 870 lb.

$$F = \frac{W}{G} \times \frac{V^2}{R} \qquad F = ?$$

$$= \frac{5}{32.2} \times \frac{53^2}{.5} \qquad W = 5$$

$$= 870 \text{ lb.} \qquad G = 32.2$$

$$R = 6'' = 0.5 \text{ ft.}$$

$$V = \frac{2\pi \times 5 \times 1{,}000}{60} = 53$$

If the speed is doubled the inertia force will increase as the square of the speed, or will be four times as great. This accounts for the rapid increase in vibration with only a slight increase in speed.

Balance, Free (Unloaded). Consider the balance of the crankshaft when free, that is without rods attached. First look at it from the static viewpoint.

If the shaft is held on centers, or on knife edges, the heaviest part of the crank will always drop to the bottom, as shown in Fig. 119. Such a shaft could not be expected to be in a running balance. In order to get

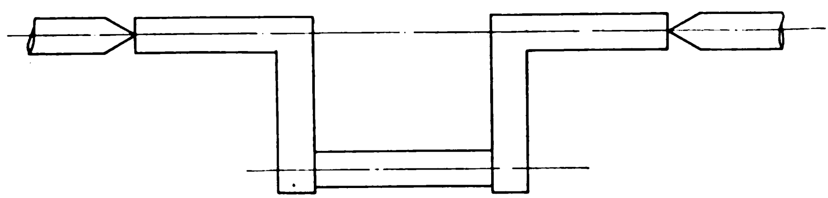

FIG. 119.—Unbalanced crankshaft.

the shaft in static balance, it is necessary to add to it a mass of sufficient weight to balance the heavy side. A 2-cylinder shaft can be so constructed very easily. See Fig. 120. Crankpin A will balance crankpin

B, so that the shaft will be in static balance. Because there is friction between the knife edges, *C* and *D*, and the crank, it is usual to start the

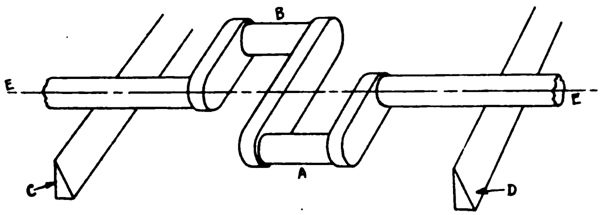

FIG. 120.—Method of testing for static balance.

shaft rotating, and note where it stops. If it stops in the same place each time it is not properly balanced.

Although this shaft is in static balance, it will not be in rotating bal-

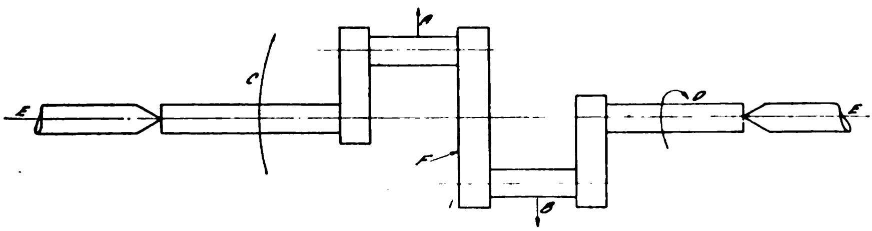

FIG. 121.—Centrifugal couple.

ance because of the centrifugal couples. As soon as rotation starts, see Fig. 121, pin *A* starts to pull at right angles to the axis of rotation *E–E*, and pin *B* also pulls at right angles to *E – E*, but at 180 degrees from *A*.

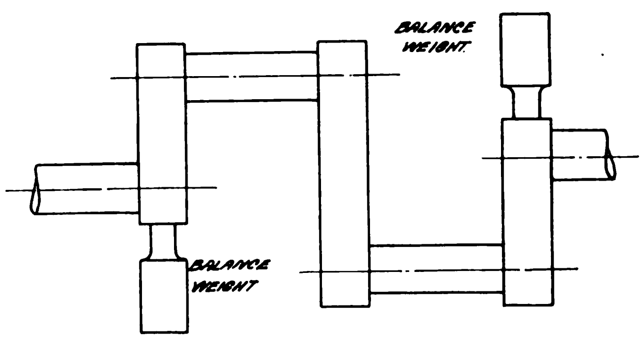

FIG. 122.—Crankshaft with balance weight.

The forces tend to cause rotation about *F* as a center in the direction of the arrow *C*, because they do not pull in a straight line.

The only way to balance this shaft is to establish in the opposite direction, an equal centrifugal couple. This can be done by adding

balance weights, as shown by Fig. 122, or by the addition of two move throws, as shown by Fig. 123.

Balance Loaded, with Rods. If the crank is in balance each connecting rod is of the same weight. When the rods are added, the crank will still be in balance. It is imperative to see that each rod is of a standard weight.

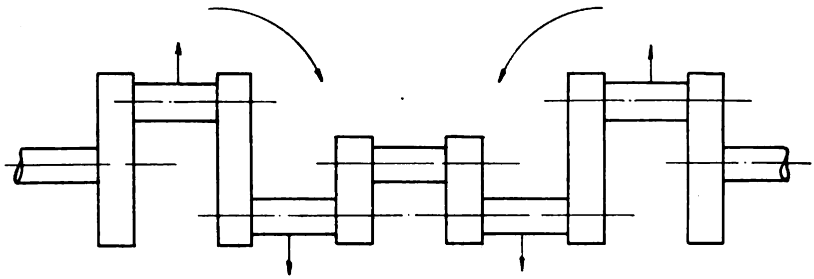

FIG. 123.—Four-cylinder crankshaft balanced for centrifugal forces.

122. Elastic Deformation. Assume that a crankshaft is in perfect static balance at 1,000 r.p.m. At this speed the shaft is stiff enough to resist bending. But when the speed reaches 1,500 r.p.m. the centrifugal forces will be more than double and the shaft will spring. When springing takes place the symmetry of the shaft is lost and the vibrations increase greatly. This bending, or springing, is known as *elastic deformation,* which means that the part will change in form, but as soon as the load is released, will return to its original shape.

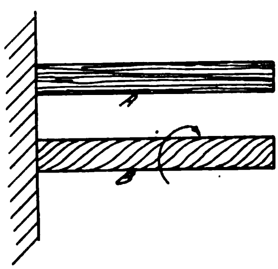

FIG. 124.—Effect of torque on a shaft.

There are three ways of overcoming this bending: by adding balance weights; by making the shaft stronger, either by changing the material or size; and by the addition of a main bearing. The last method is not advisable. The bearing must carry the load, due to the springing of the shaft, and will wear. This means that the shaft will be subject to deformation, unless the bearing is always perfectly adjusted. The first or second method is the better. The shaft must not only be stiff enough to withstand the forces established by itself, but also must withstand those loads imposed by the rods, inertia of the pistons, and explosive forces. There is another form of elastic deformation, to which the crankshaft is susceptible, known as *torsional* oscillations. They are the oscillations, or twisting, of the shaft due to the torque. Thus a shaft is shown at A in Fig. 124, which is fastened at the left end. Painted lengthwise on the rod are straight lines. Upon trying to rotate the right-hand end, the shaft will be slightly twisted,

as shown by the lines at *B* in Fig. 132. If the end is released the shaft will return to its original position, and if this is done rapidly a great amount of vibration will be generated. This takes place in all engines, but particularly in those equipped with long crankshafts. When the front cylinder fires its charge the shaft will spring considerably.

There are several types of devices intended to reduce these oscillations. Most noteworthy are of the balance, or flywheel construction. A small balance is mounted on the front of the crankshaft, as shown by Fig. 125. The inertia of the small balance wheel must be overcome, before the shaft can twist.

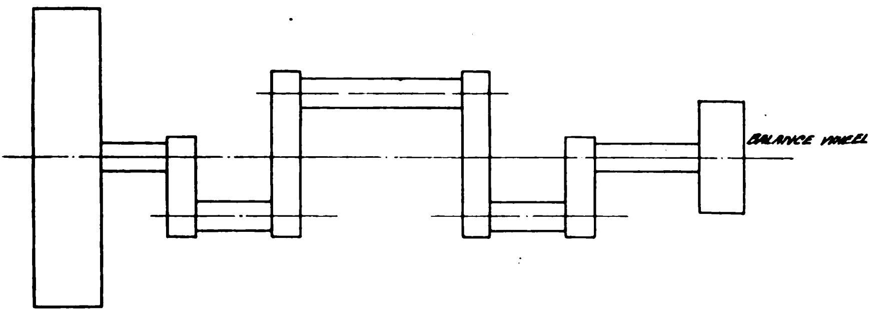

Fig. 125.—Balance wheel to reduce torsional oscillation.

Critical Speed. Every piece of apparatus has a definite period of vibration. When the frequency of the vibrations, due to the torque of the engine, approaches the periods of vibration of any part, or parts, these vibrations are increased in magnitude. If the frequency of the engine vibrations exceeds those of the parts, no increase in vibrations takes place. As an example, consider the automobile. At a certain speed there is practically no vibration. Increase the speed a little and the entire car starts to vibrate. With further increase in speed this vibration may stop.

The critical speed of a shaft is that speed at which its elastic forces are completely neutralized. At this point it is incapable of offering any resistance to a deflecting force. It is the speed at which the shaft will stop rotating about its geometive center, and rotate about its true center of gravity. The term *critical* speed as applied to a unit is slightly different. It is that speed at which the vibrations are at a maximum in frequency and magnitude. If the speed is increased, they will decrease. Thus the Liberty engine had its critical speed at 1,450 r.p.m. with the light crankshaft, when mounted in the HS-2L boats. With the medium-weight shaft the critical speed was 1,500 r.p.m., and with the heavy 1,550 r.p.m. In other planes and with other equipment these speeds will vary.

There are two reasons for desiring a reduction in vibration. First, vibrations will crystallize and break shafts, wires, and frames. For this

reason wooden supports are used, almost entirely, for aircraft engines. Second, the annoyance to the pilot is considerable. He has enough to contend with, without being bothered by unpleasant vibrations. If the usual operating speed of the machine is 1,500 r.p.m. it is desirable to get the critical speed either above or below this value.

Because a certain engine and plane vibrates excessively does not condemn the units. The combination is faulty. The same engine in another plane may work well, or the same plane with another engine may be successful. Thus, an engine which vibrates in unison with the plane, at normal speed should not be selected.

123. Torsional Reaction. Another factor causes vibration, aside from the torsional oscillations. This other force is due to the piston side thrust. When an explosion occurs the piston is forced down and sideways. This causes a rocking motion in the frame. In order to reduce this action to a minimum it is customary to add to the number of cylinders. This will reduce the magnitude of the individual impulses. Remember that a steady force does not cause vibration. It is the periodic changes of the force, either in direction or magnitude, that causes the vibration.

A single-cylinder engine will cause a side thrust of a certain magnitude and frequency. Doubling the number of cylinders will double the frequency, and make the side thrust more constant. The greater the number of cylinders the nearer the approach to a constant push on the cylinder walls. This type of unbalanced force will rock the whole engine and framing.

CHAPTER IV

GASOLINE CARBURETORS AND CARBURETION

Mixture-making Problems

Note.—In order to present the carburetor and carburetion work intelligently, the general mixture-making problem must be considered in detail. These details, or problems must then be reconsidered, amplified and studied in greater detail, followed by a study of carburetors.

124. Vaporization of the Fuel. Vaporization of the liquid fuel means changing the liquid into a vapor or gas. Simply breaking the fuel into a minute spray does not imply vaporization nor is the fine spray the essential condition in the burning of the fuel. Before the fuel can give off heat in combustion it must have supplied to it the latent heat of vaporization, which will change the liquid into a fuel-vapor. Vaporization is a purely physical change in the state of the fuel. It will remain in the same chemical form but be changed from a liquid to a gas.

Vaporization is purely a fuel and heat problem and is not dependent upon the carburetor. If the heat is supplied the fuel will be vaporized independently of any other factors.

Effect of Degree of Atomization. A cubic foot of ice in the form of a block will not melt as rapidly as the same volume of ice when broken into fine particles, because the later presents more surface area through which to receive the latent heat. The same effect is noticed between a coarse and a fine spray of fuel. The fine spray presents more surface to the air, and as a result, the latent heat is supplied to the fuel more quickly, increasing the rate of vaporization. Therefore, from the vaporization standpoint, a maximum fineness of spray is desired. This of course is a function of the carburetor.

Effect of Temperature on Vaporization. Water will evaporate more quickly on a hot, dry day than on a cold, dry day, because the temperature is higher. In a like manner the fuel will vaporize more rapidly when the temperature of the air is high, therefore, in order to aid vaporization a high temperature is desired. Another fact makes it essential to keep the temperature down. This will be given consideration later.

Saturation Temperature, Quality of the Fuel. By saturation temperature is meant the lowest temperature with a given pressure at which a liquid can exist as a vapor. This is very important, for if the engine is using a fuel which can not exist as a vapor below 32° F., and the temperature of the air is 0° F., it will be impossible to start combustion. It

is then necessary to use a different fuel, or to increase the temperature. The saturation temperature is dependent upon the specific gravity of the fuel. A fuel (high specific gravity) has a low saturation temperature and is therefore desired for use in cold weather.

To sum up the factors directly affecting the vaporization of the fuel, and to classify those desired, the following should be noticed. (*a*) The total latent heat must be supplied for complete vaporization. (*b*) In order to accelerate vaporization a maximum atomization, or fineness of spray coupled with a high temperature and a low saturation temperature is desired.

125. The Carburetor. The carburetor's main function is the proportioning of the fuel and air. It must meter a predetermined quantity of fuel to a predetermined quantity of air. An ideal carburetor would supply the correct air-fuel ratio at all times, and would not be effected by pressure, temperature changes, or the quantity of mixture flowing. Besides the above, the mixture should be homogeneous or uniform. In other words, all parts of the mixture should be of the same air-fuel ratio. This property can be obtained by a proper mixing of the fuel and air in the carburetor. There are many ways of obtaining the desired results. These methods will be considered under 'Carburetors."

Atomizing or Spraying the Liquid. Atomizing, or spraying the liquid fuel is frequently used, as it is the only way that different carburetors will effect vaporization. A maximum fineness of spray as previously explained, is desired to produce homogeneous vaporization Besides these features a minimum resistance to the flow of air is essential with wide-open throttle as at low speed the throttle imposes the necessary resistance to reduce the charge weight, but at high speed the throttle is opened wide to reduce the flow resistance, and it is at this time that carburetor resistance is important. It explains one of the differences between the carburetor for racing automobiles and pleasure cars.

126. The Intake Manifold. The intake manifold has as its function the transportation of the fuel-mixture. It receives the mixture from the carburetor and must deliver it to the cylinders. Like a railway system, its first job is to deliver the goods in the same condition as when received. Applying this to the manifold, it must deliver the mixture to the cylinders at the same density, at which it left the carburetor, and in the same air-fuel ratio.

The proper air-fuel ratio is easily obtained if the mixture is dry, but if wet, all cylinders will not get the same charge due to the inertia of the liquid.

Consider a manifold designed as shown in Fig. 126. At low speed No. 1 cylinder will get most of the liquid fuel when the mixture is wet, but at high speed the mixture velocity may be so high that the liquid fuel will pass No. 1 cylinder and enter either No. 2 or No. 3 cylinders.

In addition to this the manifold must function properly at all speeds. It must supply to each cylinder at any speed the mixture as released from the carburetor. At low speed, with a large manifold, the air velocity may be so low that, if the mixture is wet, the small drops of liquid will not be carried to the cylinder. In order to remedy this a manifold giving a higher air velocity is necessary. That is, the manifold must be of such construction that difficulties in lifting the liquid while idling will be eliminated.

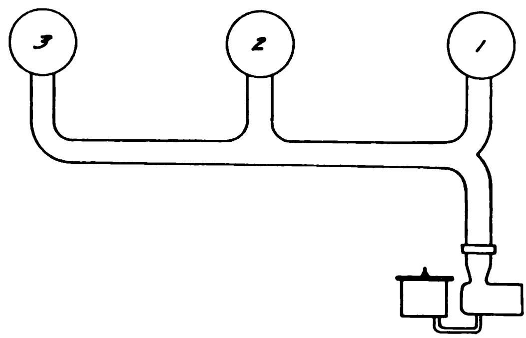

FIG. 126.—Three cylinders fed by one carburetor.

127. Mixture-making Apparatus vs. Engine Action. *Effect of Wrong Proportions.* If wrong proportions are supplied by the carburetor the operation of all cylinders will be affected. In other words, if one cylinder shows faulty operation it is not the fault of the carburetor. Even if the carburetor supplies the correct proportion and the manifold does not function properly, individual cylinders may fail in operation due to rich or too lean mixtures.

The conclusion is, therefore, not to blame the carburetor if individual cylinders fail to operate. Poor operation may be due to poor distribution. Poor distribution is unknown if the mixture is dry.

Effect of Wet Mixture. If the fuel enters the cylinder in the liquid state it has two detrimental effects. Oil contamination takes place. This is more marked in winter than in the summer, because more heat is supplied in the summer giving a drier mixture. Carbon deposits increase with the wetness of the mixture. These cause much trouble especially in high-compression engines operating at high temperatures.

Supplying Mixture to Cold Engines. In order to start an engine, it is necessary to supply the correct, or nearly correct, air-fuel vapor ratio. Simply supplying the correct air-fuel ratio is not sufficient as the fuel must be in the form of a vapor. This can be done by initial heating or by priming.

Priming. Priming is the addition of sufficient light liquids to supply the necessary vapor. It can be done by injecting either, light gasoline,

or other light fuel directly into the cylinder through pet cocks or through exhaust valves; also by altering the proportions supplied by the carburetor. This last operation provides excess fuel, a small portion of which, on vaporizing, will furnish a combustible mixture. Although a heavy fuel is used, there is some light fuel present and using a large quantity of heavy will supply sufficient of the light to start combustion.

Initial Heating. Initial heating is accomplished by filling the jackets with hot water; wrapping the manifolds with hot wet rags or heating the air which enters the carburetor. This last method will be explained in a later chapter.

Manœuvering Characteristics. There are four main factors, affecting engine operation, not dependent upon maximum power or efficiency. In aircraft work especially, maximum power or efficiency are considered of prime importance. A carburetor may meet these requirements perfectly, and yet not be suited to the work, unless the instruments meet the following requirements:

(*a*) *Idling.* The carburetor must function at this speed although not called upon to do so often. When the throttle is closed the engine should continue to operate at reduced speed. If it stops while idling the manœuver may fail, resulting perhaps in the death of two or three men, and the destruction of the airplane.

(*b*) *Acceleration, Positive and Negative.* If the carburetion fails to supply the proper proportions when the throttle is suddenly opened or suddenly closed it is not satisfactory.

(*c*) *Altitude Compensation.* Some device must be applied to the carburetor, operating either automatically or manually, whereby the engine will function at all altitudes.

(*d*) *Speed Variation.* When the spark and throttle are fixed the speed may vary, as in climbing or descending. It is a function of the carburetor to maintain proper proportions under these conditions.

Pulsating in Relation to Non-pulsating Flow. A carburetor designed for non-pulsating flow will require different adjustments for the pulsating flow. An extreme example of pulsating flow is a slow-speed, single-cylinder engine, and an example of non-pulsating flow is a high-speed, multi-cylinder engine supplied by a single carburetor. Pulsating flow through the carburetor is very apparent with 4-cylinder engines, operating at speeds below 600 r.p.m. If the carburetor is equipped with an air valve, an inspection will show that the valve opens and closes with each piston stroke, whereas, at high speed, it will not have sufficient time to close. The dash pot and other devices are added to overcome the pulsations of the valve. If it were not for the difference in density, which affects the inertia of the gasoline and air, no difficulty would be encountered due to pulsating flow.

Mechanical Difficulties. Aside from the factors previously mentioned,

which pertain to proportionality, there are some purely mechanical problems which present themselves. These are enumerated below.

(a) *Clogging.* Sand, dirt, threads, sawdust and waxes sometimes enter the carburetor with the gasoline. It is necessary that the instrument function properly despite these obstructions.

(b) *Tilting.* The plane must operate at various angles; it must climb and descend, bank to the right and left. The carburetor must be of such construction that it will not cause the fuel to leak from the float chamber or from the jets, or change fuel proportions, under these conditions.

(c) *Spilling.* No float chamber can resist spilling for if the carburetor vibrates and no fuel is being drawn, the float valve will become unseated allowing the fuel to escape. A sudden shut-down will cause the liquid to overflow and perhaps result in a fire. All carburetors will spill, but the one least susceptible to it is desired.

(d) *Air Valves.* When a back-fire occurs with a carburetor equipped with an air valve, the valve will close and cause a sudden increase of pressure in the carburetor. There are cases on record, where flanges and manifolds have been ruined by such occurrences. It is therefore essential to provide a carburetor which has an unobstructed air passage.

DETERMINATION OF ENGINE ACTION

128. Determination of Unequal Power Distribution. *Indicator.* By using an indicator, a graphic representation of the varying pressure in the cylinder can be obtained. From it the actual power developed by each cylinder can be computed. This method is excellent for slow-speed engines, but with the high-speed aircraft engine, difficulties present themselves, and as a result, a different method must be resorted to. If the test is to determine the power output of each cylinder, no adjustments should be made on the engine, but if the manifold test is to determine their relative charge-distributing ability, each cylinder must be in the same condition, that is, all of them must have the same compression, valve timing and spark advance. There are two methods of using the dynamometer to obtain the desired results, namely at constant speed and constant torque. The first method to consider will be constant torque, that is, keeping the load constant and measuring the speed with various cylinders short-circuited.

Example. A 4-cylinder engine, mounted on a test stand and operating at 2000 r.p.m. may be considered. If each cylinder is developing an equal amount of power, short-circuiting each cylinder will cause an equal speed drop. If with No. 1 short-circuited, the speed drops to 1200 r.p.m. then it should also drop to 1200 r.p.m. with either of the other cylinders short-circuited. A wet mixture is the only objection to this method.

Short-circuiting one cylinder will cause a decrease in the rotation speed which will vary the velocity of the gas through the manifold. This will vary the charge supplied to the various cylinders.

Fig. 127 represents a 4-cylinder engine fed by one carburetor through a manifold of conventional design. At high speed the gas velocity may be so high that the drops of liquid will pass ports No. 2 and No. 3 and enter in greater quantities ports No. 1 and No. 4. Thus cylinders No. 1 and No. 4 will get excess fuel. It is, therefore, evident that this method is not suitable. When operating at constant speed the above difficulty is eliminated. To make a test by this method place the engine on a test stand and attach some type of power-measuring device. Measure the power with all cylinders operating, then short one cylinder and relieve the brake so that the speed will remain normal.

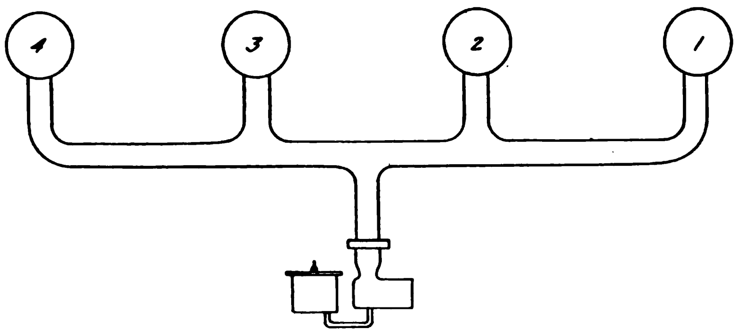

Fig. 127.—Four cylinders fed by one carburetor.

Note the power developed and subtract from the total power. This represents the power developed by the cylinders which has been cut out. Do this for each cylinder and then compare results.

Example. Fig. 127 represents an engine which develops 80 hp. while operating at 1500 r.p.m. With No. 1 cylinder shorted it developed 60 hp.; with No. 2 shorted 50 hp.; No. 3 shorted 40 hp.; No. 4 shorted 65 hp. Subtracting from 80 it is found that the power developed by each cylinder is as follows: No. 1, 20 hp.; No. 2, 25 hp.; No. 3, 40 hp.; and No. 4, 15 hp.

The first thing observed is that these powers sum up to 100 hp., while the engine actually develops only 80 hp. This is a result of the elimination of the power developed in the cylinder by cutting off the spark being indicated horsepower. If the indicated horsepower of an engine is desired, short each cylinder in turn as explained above, and total the power developed by the various cylinders. Thus the indicated horsepower of the engine under discussion is 100; the brake horsepower 80, and the frictional horsepower 100 minus 80 or 20 and the mechanical efficiency $\frac{80}{100}$ or 80 per cent.

129. Mixture-quality Analysis. By mixture quality is meant the approach to a perfect air-fuel ratio. This can be determined by two general methods, chemical and sight. The latter is the more applicable to airplane work because of the ease with which it can be used.

Chemical. A sample of the exhaust gases can be taken and analyzed by means of the usual Orsat Apparatus. The desired analysis should show carbon dioxide (CO_2) which is the product of the combination of carbon and air and water (H_2O) which in turn is the product of the combustion of hydrogen and air. There will be nitrogen and other inert gases present, but it is the carbon dioxide and water which are of interest.

If combustion is not complete, either carbon monoxide or oxygen, or both, will be present, in addition to carbon dioxide and water. Carbon

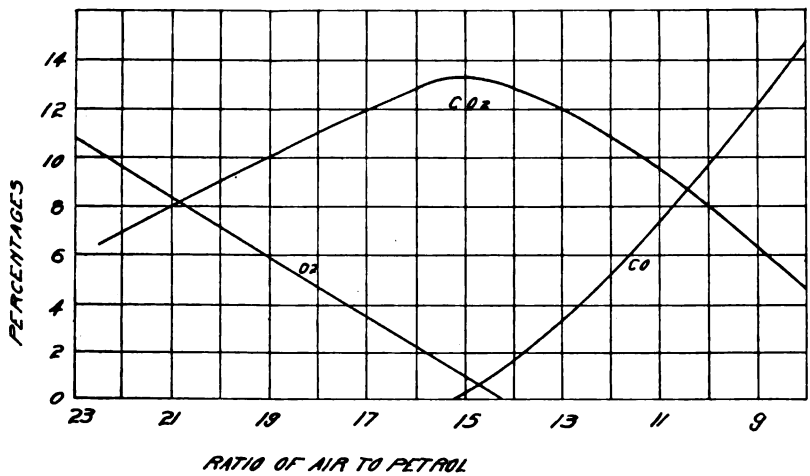

FIG. 128.—Exhaust-gas analysis curve.

monoxide shows that there was excess fuel present, and oxygen indicates that there was excess air present. If the mixture is dry and correct, no free oxygen and no carbon monoxide will be present in the exhaust gases. If wet, this is impossible. Reducing the fuel supplied will reduce the carbon monoxide to a certain point, but before that point is zero, oxygen will begin to appear, as shown by Fig. 128.

Exhaust-gas Analysis. (*a*) *Sight Method.* Noting the shape of the exhaust flame and its color is a very satisfactory method for determining the mixture quality in actual operation. By experiment, determine the flame shape and color which gives the desired horsepower or efficiency and keep this as a standard. Then by simply noting the colors of the flame, when the engine is operating, the quality of the mixture can be determined. Special attention is called to the fact that the shape and color of the flame varies with the compression pressure, valve timing,

fuel used, and many other factors. Therefore each engine will have its own characteristics as to the flame, but in general the following is true. The exhaust of a rich mixture shows a red flame. If exceedingly rich the flame will have some black coloring. The flame may be long, or short, and issues forth in spurts. As the mixture decreases in richness the flame becomes long and blue.

A correct mixture shows a cone-shaped blue flame. If working for maximum power, the flame should be long and of a deep blue color. If working for maximum efficiency, it should be short and light bluein color. A weak mixture shows a short, snappy flame, varying in color from a whitish-blue to a yellow, as the weakness increases. Attention is again called to the fact that these characteristics will vary slightly with different engines and conditions. Therefore a standard should be set at each air station for each type of engine.

130. Combustion Rate. Variations in proportion will produce variations in rates of flame travel. This can be noticed by the spark advance necessary to get a definite speed from an engine. Assuming that a 30° spark advance is necessary in order to have the engine rotate at 1500 r.p.m., when using an air-fuel ratio of fourteen to one, then an increase in ratio to 15 to 1 will reduce the spark advance to about 25°.

Variations in Quality of the Fuel Used. Variations in fuel used will show similar results. Noting the spark advance necessary will give a good indication of the relative rates of flame travel. A light fuel will give the highest rate of travel because it will contain a greater proportion of hydrogen than carbon.

Different Carburetors. The changing of carburetors causes the rate of flame travel to vary. The degree of homogeneity which is effected by the fineness of spray and type of mixing tube used causes this variance. The more perfect the homogeneity, the higher the rate of flame travel as previously explained.

Mixture Making

131. Petroleum Fuels. Crude petroleum is light brown in color and rather thin, ranging from 0.5 to 1.05 in specific gravity, the average being about 0.80. There are two bases, paraffin and asphalt. When crude oil is completely distilled, the residue will be either paraffin or asphalt. Most oils from wells west of the Mississippi are of asphalt base while those from the east are usually of paraffin base. The asphaltic crudes are usually higher specific gravity, the heaviest coming from Mexican fields. The specific gravity varies greatly. Wells separated only a few miles may vary as much as 0.5 in specific gravity, but usually various sections of the country supply crudes of about the same specific gravity. The quality of the crude is not dependent upon the base. Oil quality is determined almost entirely by the method of distillation. Crude petro-

leum contains petroleum, ether, gasoline, naphtha, kerosene, lubricating oils and the heavy oils and waxes.

By the application of heat, it is possible to vaporize the crude oil. The first portions to distill are those with low boiling points, classified as gasolines. Then come those with higher boiling points known as kerosene. Next in sequence come lubricating oils, fuel oils, and other heavier oils.

Fig. 129 illustrates the distilling apparatus. The oils which vaporize first pass into the containers *A* and *B* then to *C*, *D*, *E*, and so on.

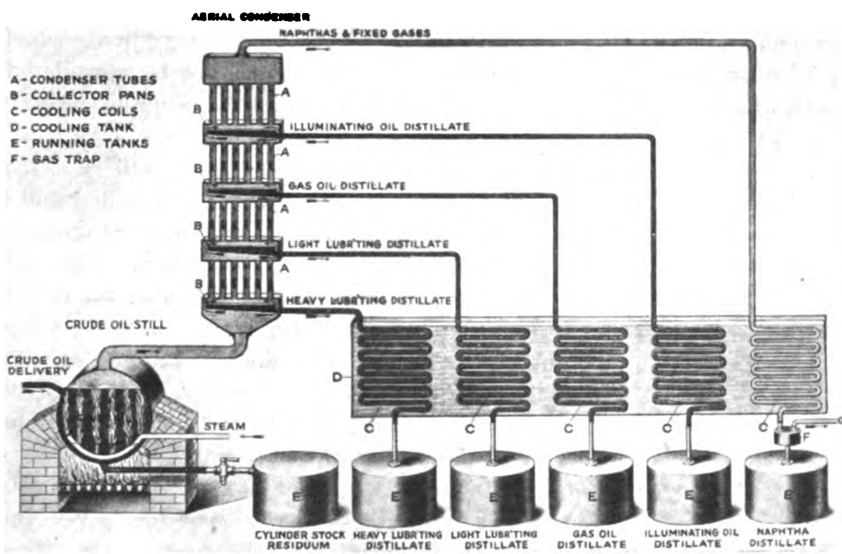

FIG. 129.—Distillation apparatus.

The time when the oil shall be cut off from *A* and deposited into *B*, that is, the amount which shall be deposited into *A*, is determined by the volatility of the liquid. Only light oils are wanted in *A*. The boiling point of the liquid determines its volatility. Assume that gasoline is to be specified as having boiling points ranging from 120° to 320° F., and kerosene from 320° to 620° F. Consider a thermometer in the line through which the vapors are passing. When the temperature reaches 320° F., tank *A* is to be cut off and the products then passed into chamber *B*. When 620° F. is reached a cut is again made and the vapors are allowed to pass into *C*.

Cracking.—When a fuel is heated to a certain temperature which depends upon its pressure, it will crack, that is, it will break up into lighter fuels and free some of the carbon. This will take place in both the liquid and gaseous state, but to a greater extent in the liquid. The

carbon that is freed will collect in the bottom of the still and forms the thick black substance, which is drained off after distillation. Petroleum fuels are all hydrocarbons and vary only in the percentages of carbon and hydrogen present. If C_xH_y represents the chemical composition of the fuel, then the fuels vary only in the value of X and Y. The lighter the fuel the smaller is the percentage of carbon present, or to refer to the formula, the smaller is the value of X. When the fuel cracks, some of the carbon precipitates, leaves the fuel with a smaller percentage of carbon, resulting in a higher Baumé reading. The carbon which precipitated will collect in the bottom of the still. The liquids which accumulate in the various tanks are known as cuts. Thus gasoline is the first cut and kerosene the second. Gasoline and kerosene are the ingredients which are of most interest in this work. The others will not be considered. It should be noted that the end of the gasoline cut is the same as the start of the kerosene in all respects.

The boiling points of the gasoline vary from 120° F. to 320° F. If a very light fuel is required, the ordinary gasoline will be redistilled and a fuel obtained with the boiling points ranging as desired, perhaps from 120° F. to 280° F. The boiling point is dependent upon the density. A heavy fuel has high boiling points and a light fuel low boiling points. Although a fuel may have a specific gravity of .70, its density may vary. Fig. 130 represents a tank full of fuel which has a specific gravity of .70. The top of it is lightest and has a gravity of .60, the bottom of it a gravity of .80. The average of these many gravities gives the average specific gravity of the fuel as .70. This is pointed out to disprove the theory that the density of the fuel indicates its quality. The proper testing method will be discussed in the latter part of this chapter.

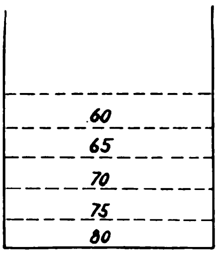

FIG. 130.—Tank showing varying densities.

The Baumé scale was discussed earlier in the course, and its relation to the testing of gasoline will be considered now. The following is a conversion table for converting from specific gravity to Baumé and vice versa. The hydrometer, for determining its specific gravity, reads in the Baumé scale. If a fuel tests 65° Baumé, its specific gravity is .73 and its density is 5.55 lb. per gal. If the fuel were a simple liquid, that is, had one boiling point instead of many, its density would be a good indication of its quality. The weight of a piece of concrete is no indication as to its features. Two pieces may weigh exactly the same but one is composed of stones well distributed and bound together with cement, while the second is composed of one large stone and the rest cement. It may be seen that the latter is not desirable. If this analogy is applied to gasoline, it must be broken up and its components inspected.

Fractional Curve. In order to test the fuel properly, it must be broken up into its parts and a temperature fractionation curve must be plotted. A fractionation curve is shown in Figs. 131 and 132. Fig. 141 represents the apparatus necessary for making the test.

Fig. 131, curve *A*, shows that one-tenth of the liquid boils at 130°; five-tenths at 160° and eight-tenths at 30°. Curve *B* shows different results.

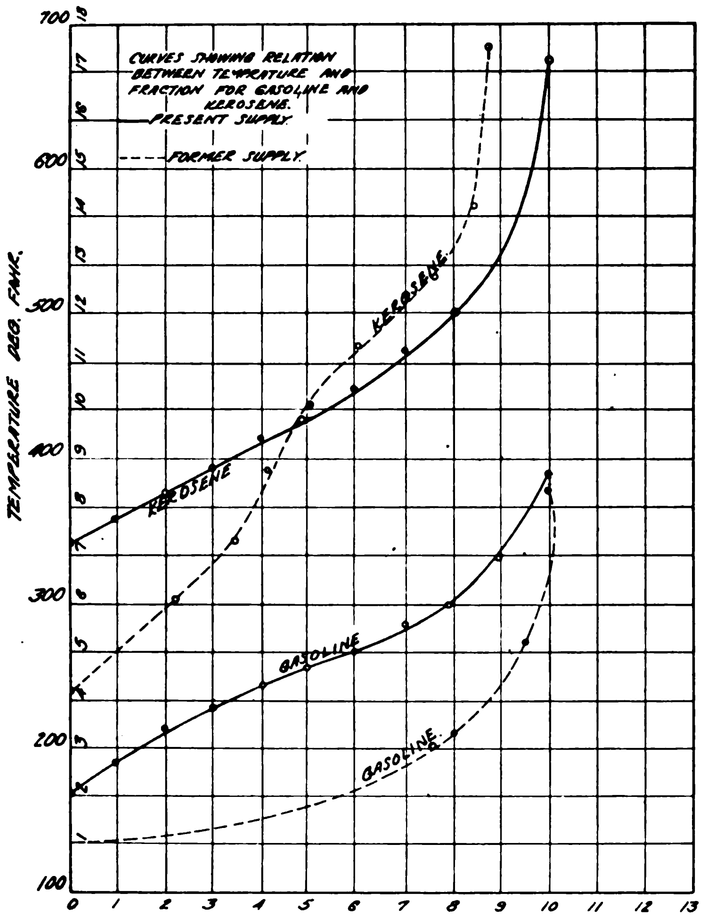

FIG. 131.—Fractionation curve.

After the first drop the temperature necessary to vaporize the fuel rises abruptly. It is very evident that the fuel giving the flat curve *A* is superior to that of *B*, from the standpoint of ease of vaporization.

Curve *A* Fig. 132, shows how its shape corresponds to curve *A*, Fig. 131. They are approximately the same. This curve is plotted as a portion of fuel evaporated versus the specific gravity and density of the fuel. Comparing the two curves, it is found that the density of the

fraction indicates its boiling point but the average density of the fuel does not indicate its volatility any more than the average of the boiling points can be said to be the fuel's boiling point.

In order to get the necessary data for plotting the above curves, it is necessary to fill the flask or still, such as is represented in Fig. 133, with a

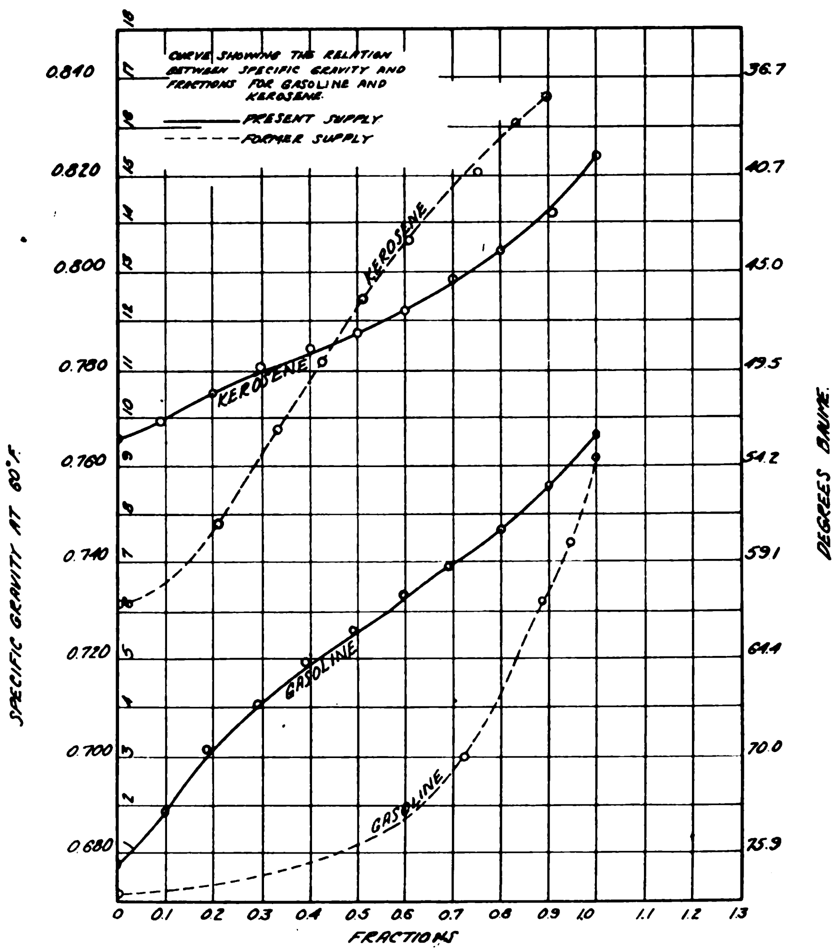

FIG. 132.—Fractionation curve.

quantity of fuel. For convenience, use 1 pt. (100 cc.), with a thermometer placed as shown. Apply heat and watch the temperature and the receiver. When the first drop has condensed and passed into the receiver, note the temperature and record it on the data sheet under the heading, "Temperature of First Drop."

Increase the heat, and when 10 cc. have passed to the receiver, note the temperature and record it on the data sheet. Continue taking tempera-

tures for every 10 cc. until all the fuel has passed into the receiver. The last temperature noted will be "Temperature of Last Drop." The temperature of the first drop and the temperature of the last drop represent the end points.

Cracking Process. If a greater supply of gasoline is desired than is normally obtainable from the crude oil, the cracking process is resorted to. The Rittman process is based on this method. The fuel is put under a high pressure and then heated to a high temperature. The result is that the fuel is cracked (some of the carbon separated from hydrogen), resulting in a light fuel. By this means a great quantity of light fuels can be obtained from the heavier products.

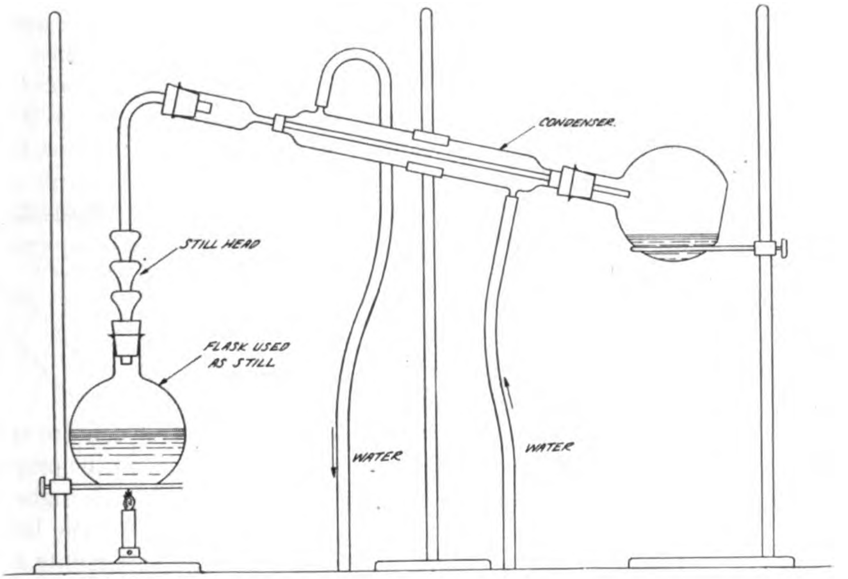

FIG. 133.—Distillation apparatus.

132. Casinghead Fuels. A few years ago it was discovered that liquids were collecting in the long pipe lines carrying the natural gas from the wells to the cities. Upon making tests, it was discovered to be a very light hydrocarbon fuel, ranging in degrees Baumé from 80 to 90. Then various types of apparatus were constructed to absorb the fuel from the gas and then to conduct the gas to the cities as before.

Fig. 134 represents the apparatus for removing the fuel by the squeezing process.

In passing out of the ground the gas picks up some very light gasoline in the form of vapors. If the gas is cooled, the vapor will condense.

The gas is first compressed to about 40 lb. pressure and then cooled by a condenser. This will cause 15 to 30 per cent. of the fuel to pre-

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cipitate or condense. At the bottom of the condenser is placed a chain for removing the condensate. Then the gas is again compressed but this time to 200 lb. It is again passed through a condenser and more fuel is condensed after which the gas is conducted to the city. This process yielded in 1915, an average of 2.57 gal. per 1,000 cu. ft. of gas.

The chief objection is its extreme volatility and bad odor. It is used for producing gas in air-gas machines and for blending fuels, the latter being its principal use.

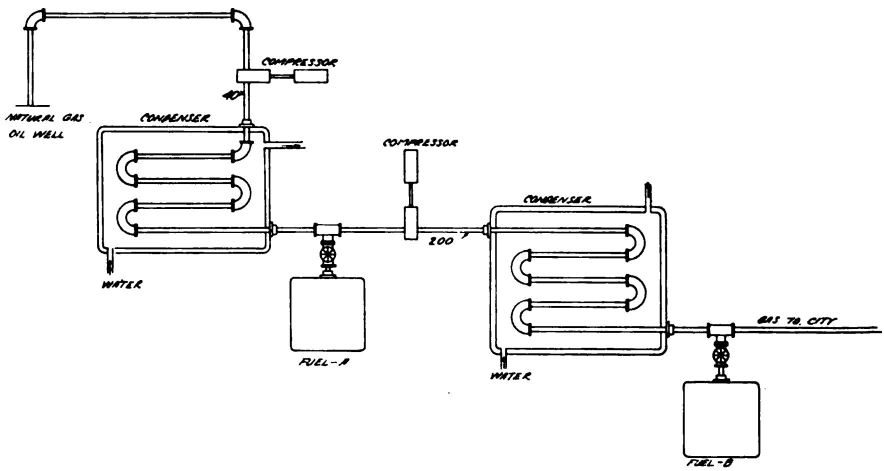

FIG. 134.—Apparatus for production of casinghead.

133. Blended Fuels. If specifications call for a fuel of definite specific gravity, it may be obtained by adding to some heavy fuel the proper quantity of a lighter grade. The light fuel usually used is casinghead gasoline. Its principal value is that it provides a market for the large quantities of heavy gasolines. The desired gravity and end points can be obtained, but the fractional curve is steep rather than flat, which is undesirable. The fuel gives sufficient vapor to facilitate starting, but unless a great quantity of heat is added to vaporize the upper ends there will be excess carbon deposits in the engine cylinders.

134. Vaporization. Vaporization is a physical change in the state of the fuel. But in order to effect this change, it is necessary to supply the latent heat of the liquid. All of the latent heat must be supplied or the fuel will not be completely vaporized.

The latent heat of the fuel is not constant but varies with the density. The greater the density the lower is the latent heat. From this it would seen that a heavy fuel would be easier to vaporize than a light one. However it is not because the heavy fuels have a high saturation temperature, or a high temperature at which the vapors will form. It was previously stated that a 40° F. temperature drop in the manifold shows complete

vaporization. This is not always true. With correct proportions it is about 40° F., but it also depends upon the latent heat of the fuel. If the liquid used has a high latent heat, the temperature drop will be a little over 40° F. If the latent heat is low, it will be less than 40° F. It is very seldom that complete vaporization takes place, because if sufficient heat is supplied to effect complete vaporization, usually excessive charge heating will take place, which will reduce the power developed. A 35° F. drop will usually give excellent results.

Determination of Wetness. Vaporized gasoline is colorless, therefore, if an inspection of the gases be made as they pass up the intake riser the wetness of the mixture can be determined. To do this, cut holes in the riser as shown in Fig. 135, and insert pieces of glass. Care should be taken to see that a wire screen or other device is imposed between the eye and the glass to prevent broken glass from reaching the eyes if a backfire occurs.

When the engine is operating look through one glass while a light is held behind the other, and if nothing is visible the mixture is dry. If wet, drops of fuel will pass the glass like rain or fine spray looking like fog or the liquid will be seen climbing up the side of the riser. This method is very good for the laboratory but not adapted to plane work.

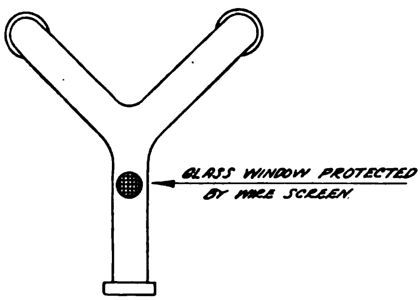

Fig. 135.—Holes in intake riser.

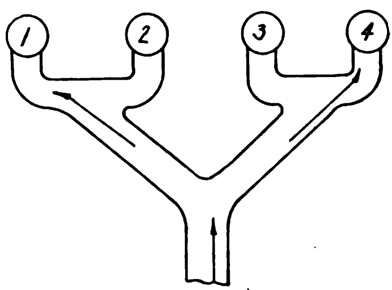

Fig. 136.—Inlet manifold with four outlets.

If two thermometers are inserted, one in the path of the air as it enters the carburetor and one in the riser above the spray jets, the temperature drop can be measured.

If the air temperature at T is 70° F. and at T_2 is 50° F., it represents a 20-degree temperature drop, which indicates incomplete vaporization. It can be remedied by adding more heat to the air before it enters the carburetor. If the thermometer dials were located on the instrument board in view of the pilot, he could tell at all times the degree of vaporization which takes place. With a valve in the hot air supply line leading to the carburetor, the amount of heat can be varied at will. Thus it would be possible to get any desired degree of vaporization.

Wet Mixture. Wet mixtures greatly decrease the ease of distribution,

because of the difference in the density of liquid and gas. If the density of the two were the same, they would have the same inertia and no difficulty would be experienced.

Fig. 136 represents a conventional manifold. If the mixture is wet, the drops of liquid will continue in the direction of the arrows and give cylinders No. 1 and No. 4 excess fuel while No. 2 and No. 3 will get a lean mixture. It is extremely difficult to secure a manifold which will deliver the charge properly at all speeds. Cylinder construction and arrangement will vary the shape of the manifold required.

If wet mixtures reach the cylinders, it means trouble eventually. Gradually the liquid will cut the oil on the cylinder walls, leak past the rings and dilute the oil in the oil reservoir. Finally, a burnt bearing or piston results. Besides this, the liquid will cause large accumulations of carbon deposits.

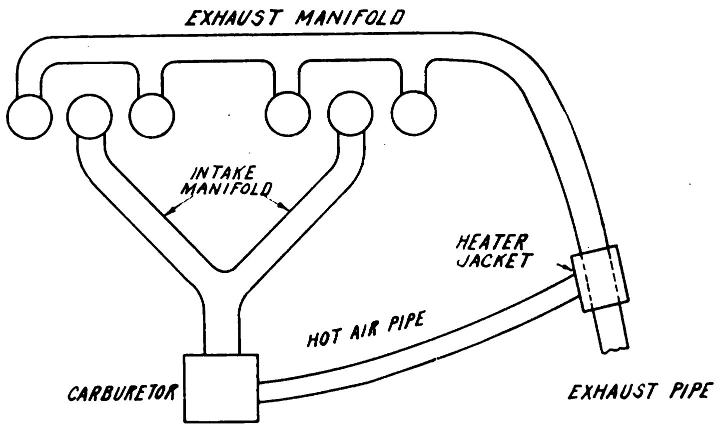

FIG. 137.—Conventional method of supplying heated air to a carburetor.

Drying Wet Mixtures. If the mixture is wet, it can be dried by the addition of heat. There are two general methods of adding heat by the exhaust gases, heating the air before the proportions are made, and heating after. The method of heating by hot water is not adequate alone, because of the slight difference in temperature between the water and the gases. With the water at 200° F. and the gases at 50° F. there occurs a temperature difference of 150° F. With exhaust gases at 900° F. and the mixture at 50° F. a temperature drop of 850° F. is obtained. This will make it possible to use a much smaller exhaust heater than water heater.

The conventional heating arrangement is shown in Fig. 137. The hot gases which enter the carburetor cause a rise in its temperature. The temperature of the fuel which decreases its viscosity, and also increases the temperature of the jets, causes them to expand.

If the jets are of the correct size to supply the proper ratio of fuel to air when the engine is cold, when it is heated, due to the great decrease in the viscosity of the fuel and the increase in jet size, the mixture will be too rich at high speed. If correct for high speed it will be too lean for starting. Therefore it is not all that can be desired.

Fig. 138 represents a venturi heater for heating the mixture after the proportions are made by the carburetor. The advantages of this device are, that there is a minimum change in temperature of the carburetor and its parts between idle and operating conditions, the heating occurring beyond the carburetor. The venturi affords a most excellent mixing device with minimum loss in pressure.

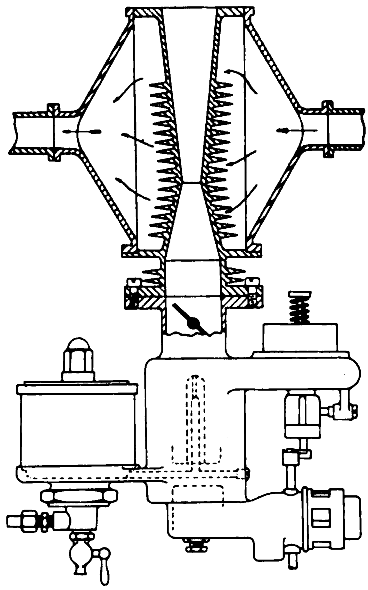

FIG. 138.—Venturi heater.

A wet mixture does not give as much power as a dry one. This is a general thought to be kept in mind, but it must be qualified. Heating the mixture does increase the power until a point is reached where the mixture is about 90 per cent. dry as it leaves the manifold. Increasing the dryness results in a decrease in the charge weight admitted to the cylinder. If the mixture is about 90 per cent. dry the remaining 10 per cent. will be dried by the hot exhaust valves and hot cylinder walls. An extremely light fuel will not give quite as much power as a slightly heavy one. This is because an extremely light fuel will usually be completely vaporized in the manifold and then the hot valves, cylinder walls and exhaust gases will heat the charge causing expansion so that a reduction in the weight of mixture delivered to the cylinder is effected. Not until a dry mixture is delivered to the cylinders is maximum efficiency obtained. As a whole, engine operation is much better with a dry mixture than with a wet one, especially with regard to maneuvering ability. The engine will not choke with a sudden opening or closing of the throttle, idling will be bettered and the carbon difficulties will be entirely eliminated. Besides this, oil contamination will be reduced to a minimum. A perfectly dry mixture leaving the manifold will cause a reduction in the power output. Only a dry mixture will eliminate all carbon troubles and oil contamination. Maximum power, minimum carbon and minimum oil contamination are desired but they can not be obtained with the same mixture condition. A compromise is necessary. Airplanes call for maxi-

mum power, therefore the engineer must determine the mixture which will furnish it. This can be done by heating the mixture until maximum power is obtained. Note the temperature drop in the manifold and keep it at this temperature all the time.

135. Carburetor Adjustments. If the mixture is dry the same needle-valve setting of the carburetor will give maximum horsepower and minimum fuel consumption. But if the mixture is wet, the needle valve will have to be opened wider for maximum power than for minimum fuel consumption. If an engine is supplied with a dry mixture, and an adjustment is desired which will give minimum fuel consumption, adjust

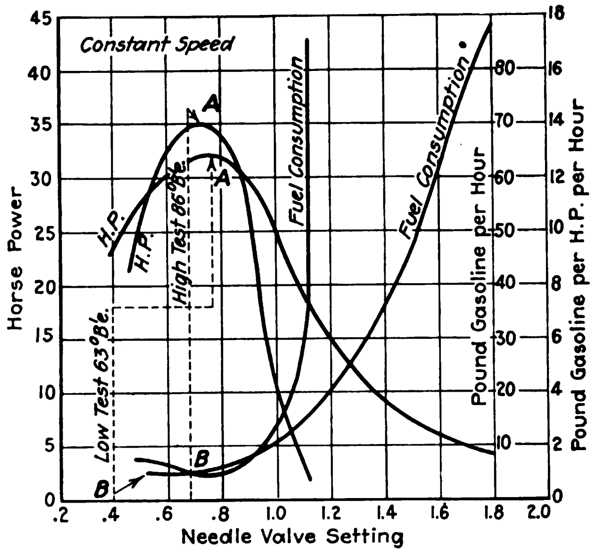

FIG. 139.—Horsepower fuel consumption vs. needle-valve setting.

for maximum revolutions per minute. This means maximum horsepower and also minimum fuel consumption, but if the mixture is wet it will be necessary to use a smaller jet for minimum fuel consumption. Fig. 139 shows the relation between the horsepower, fuel consumption and various needle valve settings.

A dry mixture can be obtained either with a light fuel or a heavy fuel sufficiently heated.

Carburetors

136. Types. A carburetor may be defined as a device for proportioning a hydrocarbon fuel with air. The early types of gasoline engines were supplied with a mixture by a very simple carburetor known as a humidifier. This was a device in which the air was drawn over the surface of the fuel, the vapor-to-air ratio depending upon the vaporization of the fuel.

Humidifiers. Humidifiers are of three general types as represented by the accompanying drawing.

Fig. 140 represents the simplest form of humidifier. In this type the air is drawn over the fuel.

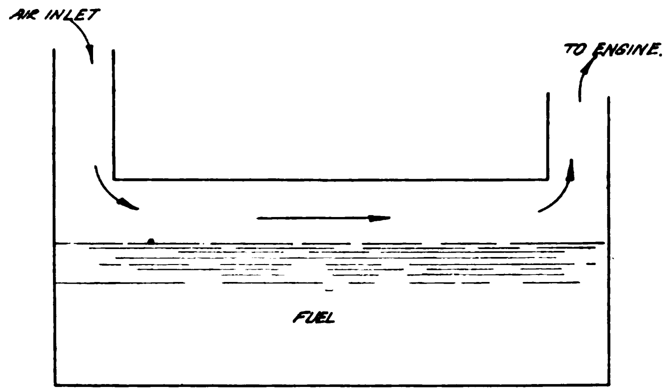

FIG. 140.—Humidifier.

Fig. 141 shows a development of the humidifier. The fuel is lifted by cloth wicks and the air passed through the wicks.

Another type of humidifier is shown in Fig. 142. The air is passed through the fuel, bubbles to the top and then goes to the engine cylinder.

The humidifier failed because the fuel used was not a simple liquid.

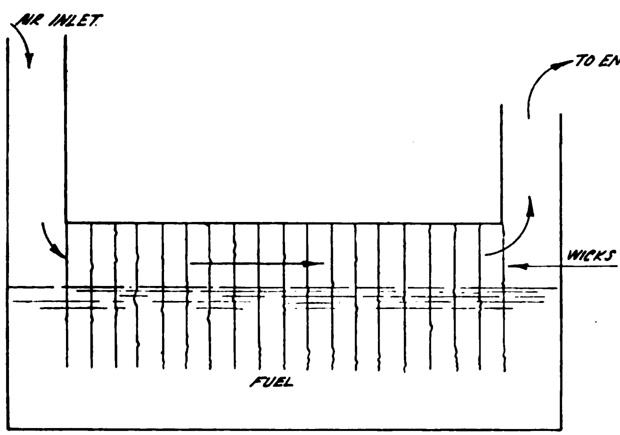

FIG. 141.—Humidifier with wicks.

The lighter fuels would vaporize first, leaving the heavy ones at the bottom of the container. In order to overcome this difficulty, mechanical metering came into use.

Mechanical Metering. At first the mechanical metering carburetors were of the volumetric type. A certain quantity of fuel was injected

or supplied to the air by a system of pumps operated by an air-driven propeller or by other means. This failed due to multiplicity of parts. At present all carburetors are of the proportional-flow type. The vacuum created in the intake manifold proportions the quantity of

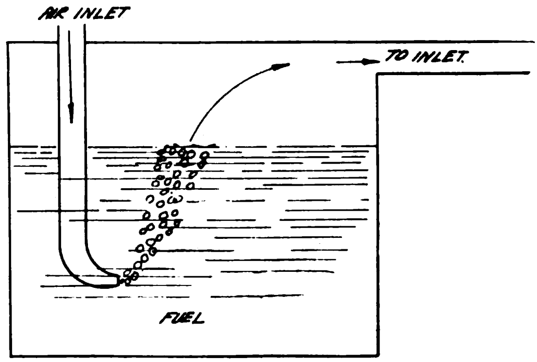

Fig. 142.—Bubbling type humidifier.

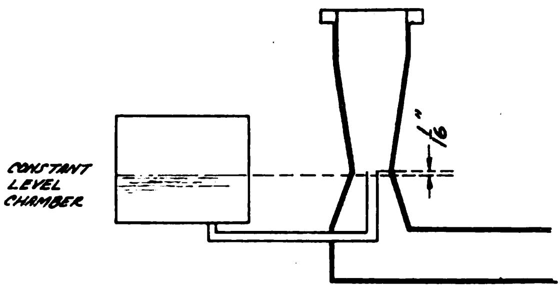

Fig. 143.—Simple carburetor.

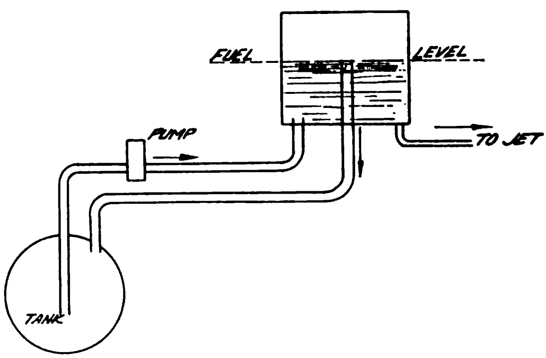

Fig. 144.—Overflow method of obtaining constant fuel level.

fuel to the proper quantity of air. All proportional-flow carburetors require a constant-level chamber, as shown in Fig. 143. The lever of the fuel must never be above that of the jets. Usually it is $\frac{1}{16}$ in. below.

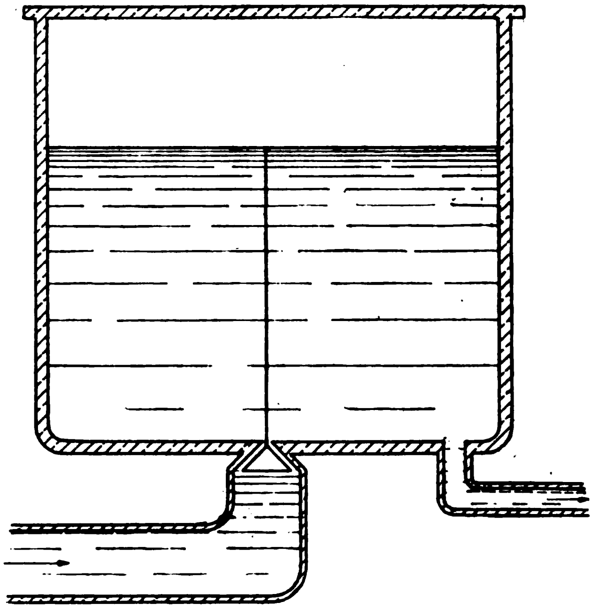

FIG. 145.—Diaphragm method of maintaining fuel level.

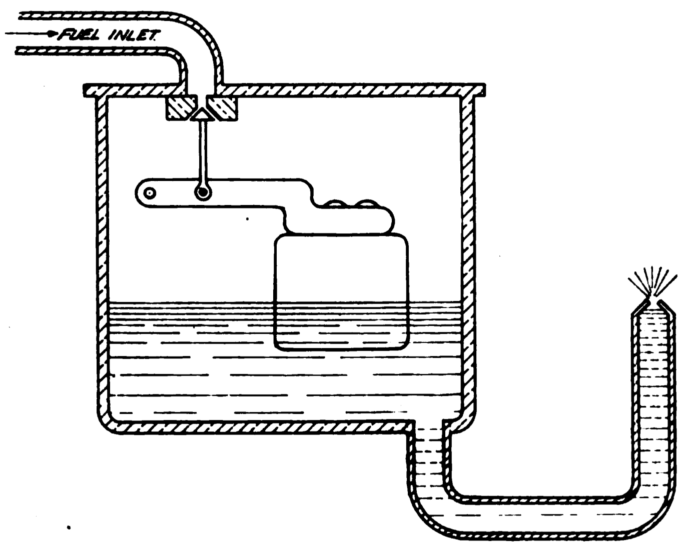

FIG. 146.—Float chamber.

137. Constant-level Chamber. The function of this chamber as its name implies, is to keep the level of the fuel at a predetermined height. The overflow system is the simplest. The fuel is pumped from the fuel

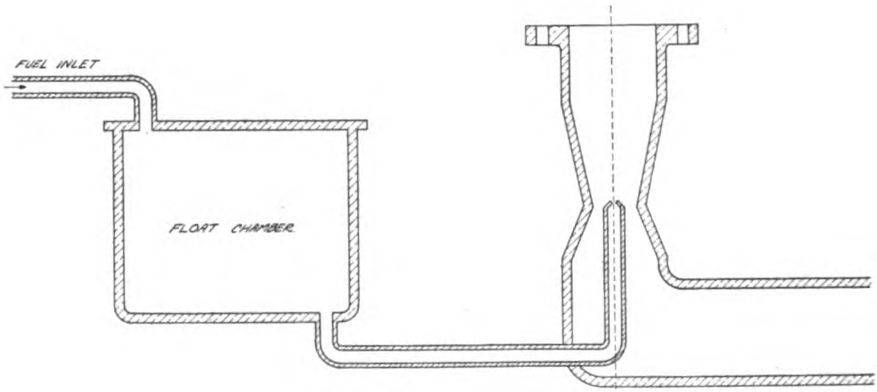

FIG. 147.—Eccentric air passage and float chamber.

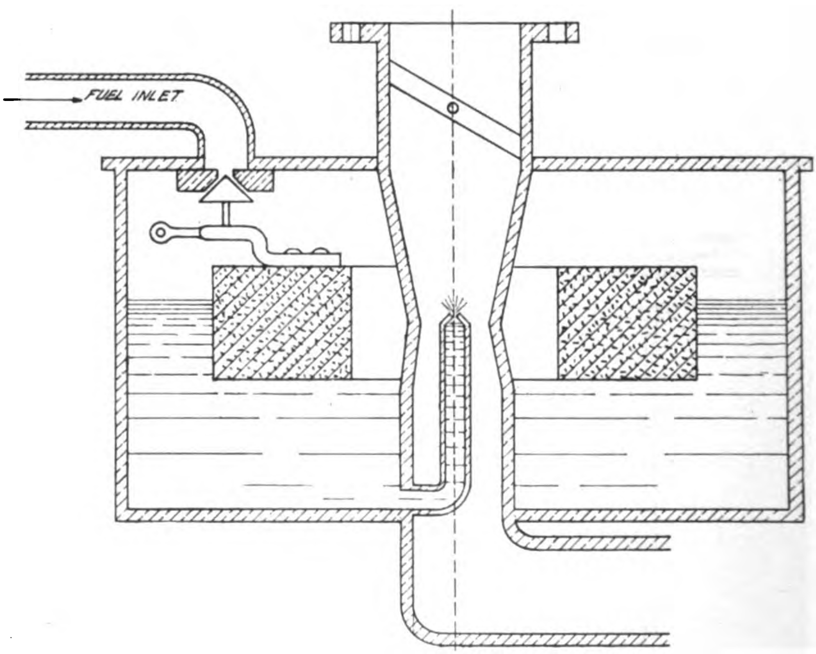

FIG. 148.—Concentric air passage and float chamber.

reservoir to the carburetor, where it overflows, returning to the tank. The disadvantage is that it requires a pump which gives trouble, is likely to spill, varies level with pump speed, and necessitates filling chamber by hand before engine starts. See Fig. 144.

The diaphragm type has been discontinued due to the difficulty of obtaining suitable material for the diaphragm. See Fig. 145.

At the present time the float chamber has superseded all other types of constant-level chambers. It consists of a float made of cork or metal

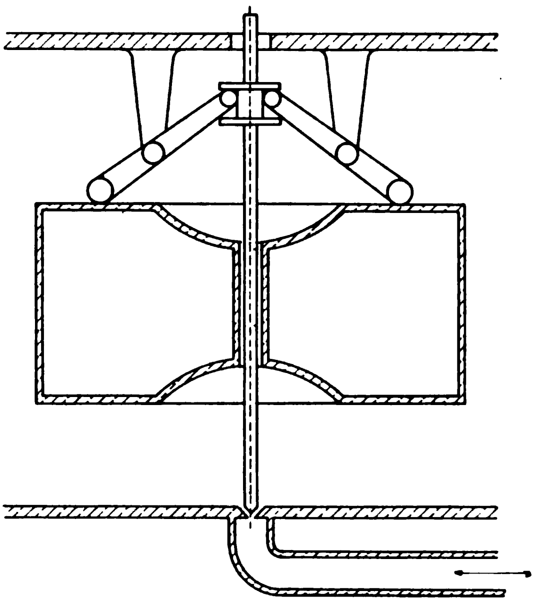

FIG. 149.—Concentric valve and float.

attached to a lever which actuates a valve in the fuel line. As the level of the fuel rises in the chamber the float rises and closes the valve in the fuel line, preventing any greater increase in the level. See Fig. 146.

There are two classes of float chamber, the eccentric and the concentric types. The eccentric chamber is eccentric with the air passage. That is, they have different centers. See Fig. 147.

The concentric type has the float chamber and air passage concentric. See Fig. 148.

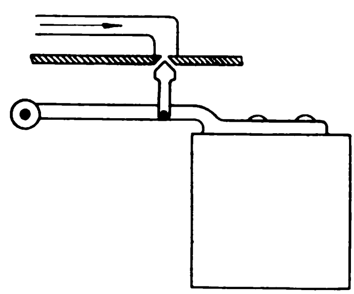

FIG. 150.—Eccentric valve and float.

Float Valves. The general use of the float chamber has brought out many types of float valves. These can be classified under two heads, depending upon the position of the float valve and the float.

The concentric valves are used in most aviation carburetors. In these, the float and valve are concentric as shown in Fig. 149.

Fig. 150 shows the eccentric type with the valve and float having different centers.

There are three methods of operating the float valves. The positively actuated is shown in Fig. 151. In this type the pressure exerted by the float closes the valves. This class is characterized by light valves, and the pressure is exerted on the top of the lower flange of the stem.

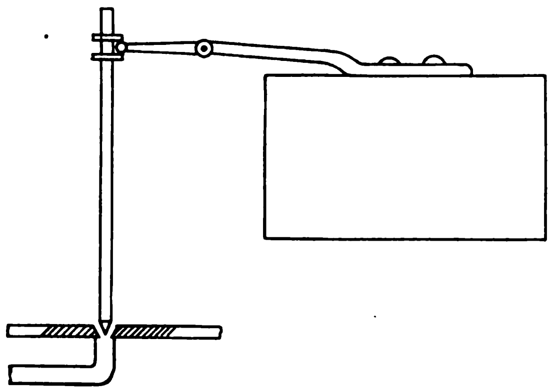

Fig. 151.—Valve closed by force exerted on float by fuel.

Fig. 152 shows a valve which is closed by its own weight. The float is of sufficient weight to unseat the valve. The valve is of sufficient weight to seat itself when the upward pressure exerted by the float is released. This type is characterized by heavy valve stems.

Fig. 153 shows the same type as that in Fig. 152 except that the valve is closed by spring action rather than by the weight of valve.

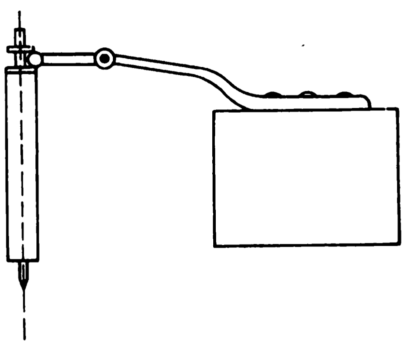

Fig. 152.—Valve closed by its weight.

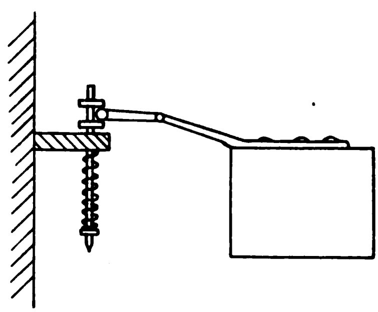

Fig. 153.—Spring-loaded float valve.

This type is characterized by light valves. It is less susceptible to vibration and spilling than the other types.

Float Valve Seats. These are located either at the top of the chamber or at the bottom. If at the top there is less liability of leaking due to

stoppage. It has the mass of the body plus the pressure of the fuel to help lift it from the seat. With the seat at the bottom, the dirt tends to lodge on the seat although the pressure of the fluid helps to remove it.

138. Air Passage. *Venturi.* This is the best type known because in addition to causing a large pressure drop at the spray nozzle which is

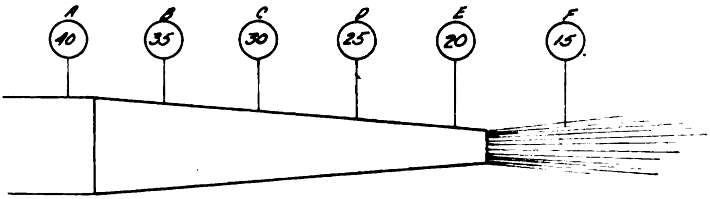

Fig. 154.—Fire-hose nozzle.

necessary to spray the fuel finely, it is an excellent mixing device. When the velocity of a fluid or gas is increased, its pressure decreases. This is proved by attaching a series of gages to a fire nozzle as shown in Fig. 154. The pressures are absolute. When the water leaves the nozzle it has the pressure of the atmosphere, which is shown to be 15 lb. at F. As A is approached the velocity decreases and the pressure builds up.

Fig. 155 represents a venturi tube. The difference between it and the fire nozzle is that it diverges after converging. It resembles two truncated cones joined at the smaller ends.

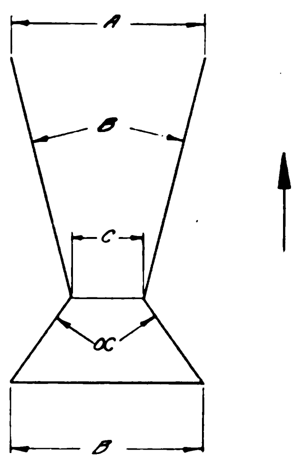

Fig. 155.—Venturi tube.

As the fluid leaves B, it increases in velocity because the same quantity which is flowing at B must pass through the smaller opening, C. This velocity increase means a pressure decrease. After the maximum velocity is reached it starts to decrease. The velocity decrease means a pressure increase. A perfect venturi would give the same pressure at A that was exerted at B. A perfect venturi is never realized but as high as 95 per cent. of the pressure exerted at B can be realized at A. This varies very greatly with the ratio of the velocities at B and C. The greater the pressure or velocity difference between B and C the less the efficiency of the tube.

A very high pressure drop is desired to obtain a fine spray but this must not be obtained at a sacrifice of the pressure of the charge going to the cylinders. With this in mind an attempt is made to get the maximum air velocity consistent with maximum charge density. This is

usually obtained when B is from 5° to 10°; OC, 20° to 50°, A equal to B and C, 60 or 70 per cent. of A. The entrance angle is not as important as the exit angle B. Fig. 156 represents a Zenith choke tube or venturi. Note the rounded corners to minimize resistance to air flow.

Besides giving a high pressure drop and then returning the charge to nearly its own pressure, the venturi combines mixing qualities which cannot be obtained with any other device.

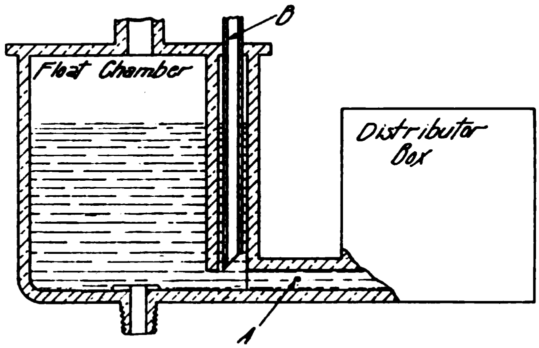

Fig. 156.—Carburetor choke tube.

Fig. 157 shows the direction of flow as the fluid leaves the tube Parallel flow takes place up to the point where the tube converges. A it diverges, the mixture leaves in whirl-pools. It revolves round and round as shown in the sketch. This results in nearly perfect mixing.

Screens and wheels can be placed in the air passage which will give good mixing but they cause a pressure drop which is undesirable.

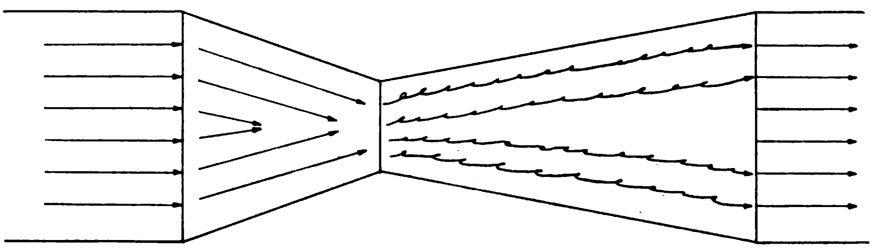

Fig. 157.—Flow condition through venturi.

Plain Tube. This type of air passage is practically obsolete at the present time but is sometimes used on stationary engines. Figs. 158 and 159 represent the two types used. The first has the fuel jet at the opening and the second has it back from the opening.

139. Orifice Flow. Gasoline increases in flow faster than air with an equal change in pressure. This is illustrated by Fig. 160. The flow is plotted as the ordinate and $P_2 - P_1$ or the pressure causing the fluid to

flow as the abscissa. There are two things to note: first, the flow of the air and fuel do not increase in the same ratio; secondly, the flow of fuel increases faster than the flow of air.

A perfect instrument would meter the same proportions at full flow as at reduced flow. Since simple openings do not furnish constant proportions it is necessary to add some device to compensate the flow. A

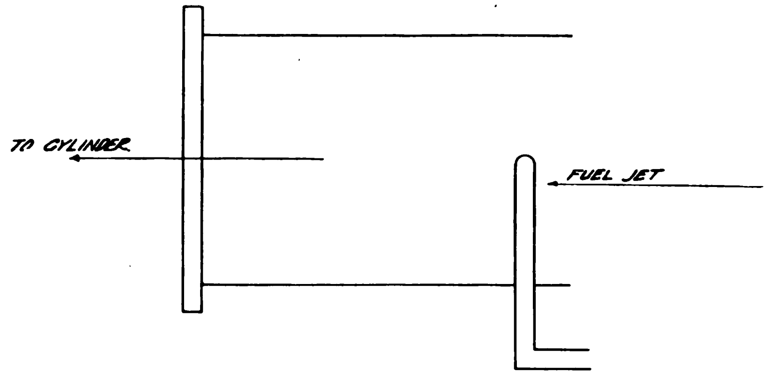

FIG. 158.—Jet at opening.

compensator is any device which will cause the flow of air and fuel to increase in the same ratio.

Effect of Viscosity Variation. A slight change in the temperature will cause a large variation in the viscosity of the fuel. Viscosity variations greatly affect the flow through a small opening. If the jets are of the proper size to supply the correct amount of fuel at the working tempera-

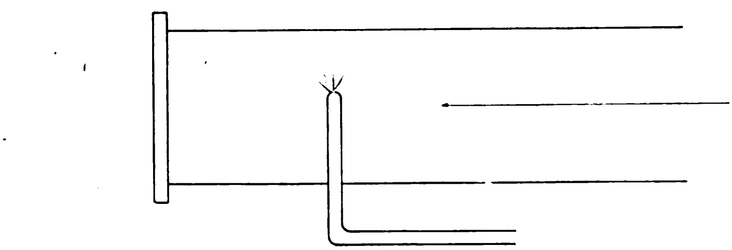

FIG. 159.—Jet back from the opening.

ture, when cold and while warming up, the jets will be far too small. It is therefore desired to keep the fuel at a constant viscosity.

Mixture quality can be defined as the approach to a correct air-fuel ratio. Fig. 160 represents a theoretical curve which shows the same ratio of fuel with closed throttle and wide-open throttle.

Actually a richer mixture is desired for idling because of the reduction in compression pressure due to large leakage of air by inlet valve stems incident to low pressure in cylinders when throttle is closed. Also the

ratio cannot be kept absolutely correct. With this in mind the curve will be changed to represent a desired quality range, a range, which if followed by the mixture will be considered good. Fig. 161 represents

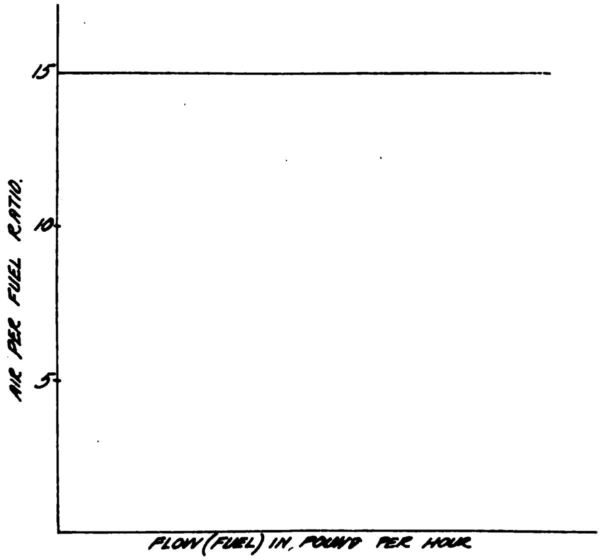

FIG. 160.—Ideal flow curve.

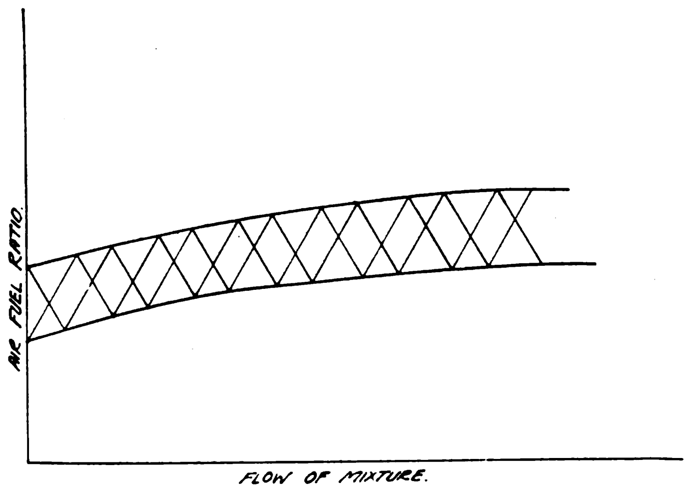

FIG. 161.—Quality range.

such a curve. If the ratio is within the shaded portion, it will be commercially correct.

140. Compensator Types. The quantity of fluid flowing is dependent upon two factors, the pressure and the area of the opening. Therefore,

it is possible to class all compensators under one of three heads: variable flow area, variable pressure head or both area and pressure variable.

Variable Flow Area. Either the area of the fuel orifice or the area of the area opening can be varied to give the desired compensation. If the fuel area is to be varied with the air opening constant, the size of the fuel jet must be decreased as the flow increases. No carburetors are made strictly upon this principle because of the extreme accuracy necessary to make the device. It is shown because of its application to another type. Fig. 162 represents such a carburetor. As the throttle opening the needle valve is partially closed, the flow of fuel is restricted.

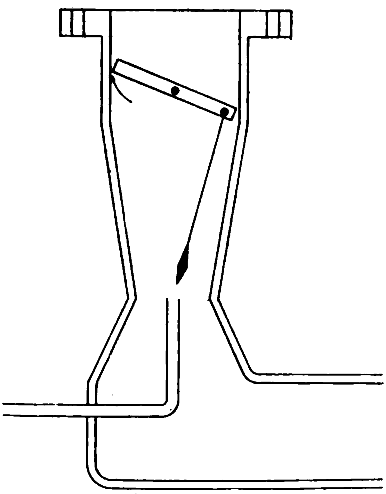

FIG. 162.—Variable fuel flow area carburetor.

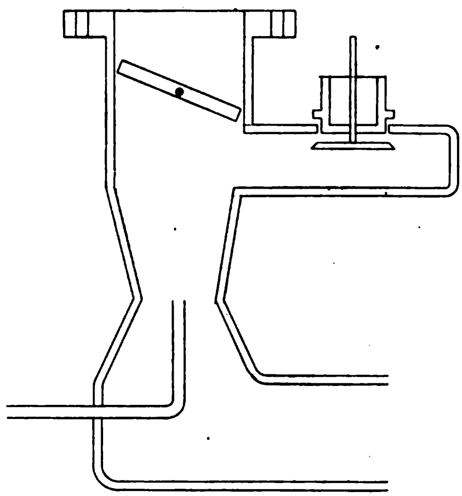

FIG. 163.—Variable air flow area type of compensator.

Fig. 163 represents a compensator operating by varying the air area. As the flow increases the air valve opens and supplies the air necessary to give the desired air-fuel ratio.

Fig. 164 represents the quality curve from a carburetor of this type. Note that as the flow increases the air-fuel ratio increases and leaves the quality range. Therefore, it is suited to an engine which operates at nearly constant speed.

In order to increase the flow range, both the air and the fuel openings are made variable as in the Schebler Models *R* and *L*. Fig. 165 shows the Model *L* with the needle valve controlled by the throttle and Fig. 166 the Model *R* with the needle valve controlled by the air valve. The latter has the advantage that the flow of fuel is proportioned by the air flow valve rather than by the throttle position.

Notice that in Fig. 165 the needle valve is raised as the throttle opens while in Fig. 166, the needle valve closes as the throttle opens.

Variable Fuel Head. The quantity of fluid discharged is dependent upon the pressure causing it to flow. The pressure is the difference between that in the float chamber and that at the spray nozzle. See Fig. 167.

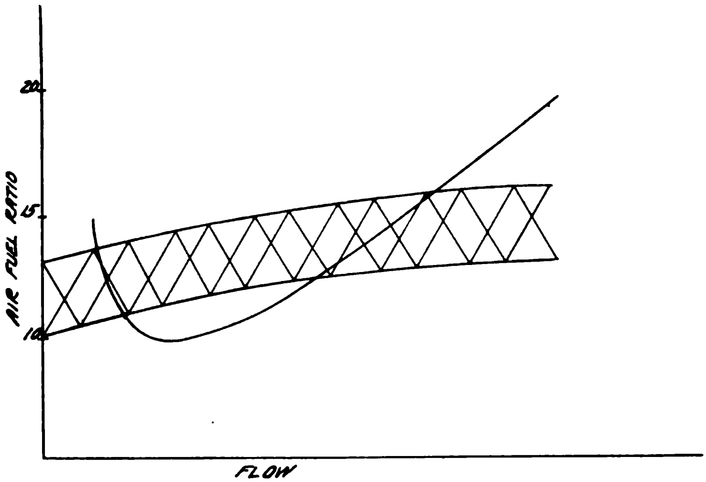

FIG. 164.—Quality curve for a carburetor equipped with an automatic air inlet.

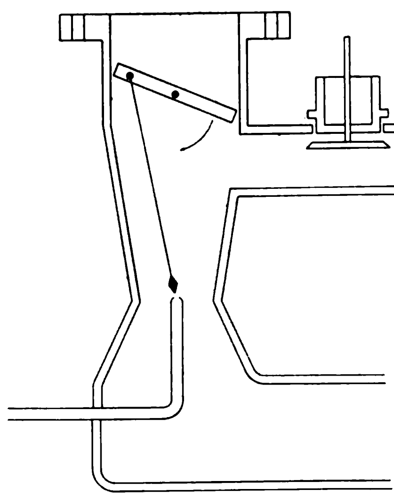

FIG. 165.—Variable fuel and air flow area type of compensator.

A compensator which varies the pressure in the float chamber is known as a variable-fuel-head type. If the valve A, Fig. 167, is properly regulated, the fuel flow can be varied as desired. It is not extensively used alone. The Zenith incorporates this principle in the altitude adjustment.

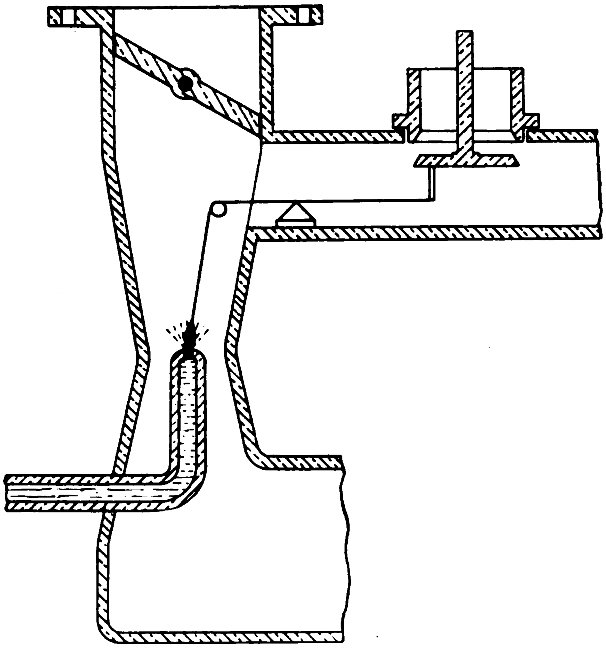

FIG. 166.—Variable fuel and air flow area type compensator with valve controlled by air valve.

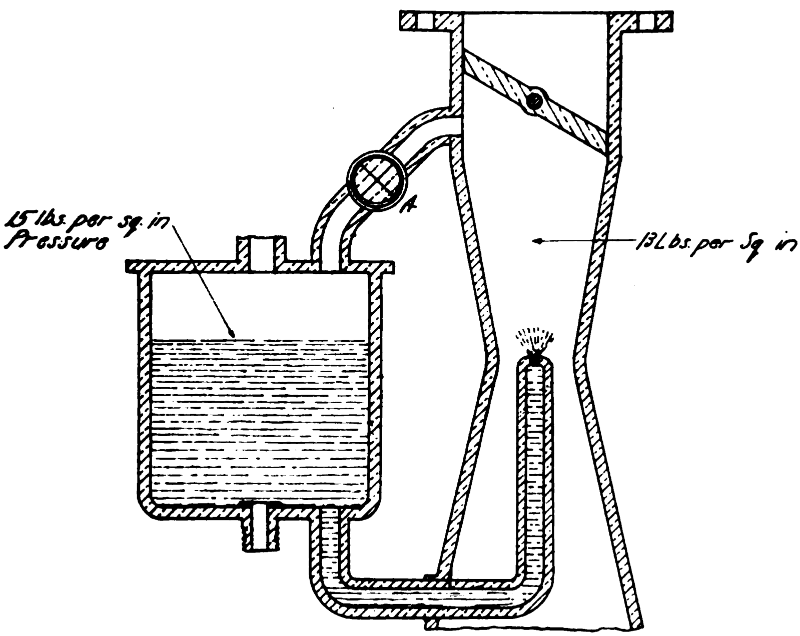

FIG. 167.—Float chamber surface pressure type of compensator.

Mixed flow is defined as gasoline and air flowing through the same channel. Reference to Fig. 168 will show that mixed flow varies the pressure causing the liquid to move. A glass is filled with a liquid and a straw placed in the mouth and dipped into the glass. Suction decreases the pressure at *A* to 10 lb. The atmospheric pressure is 15

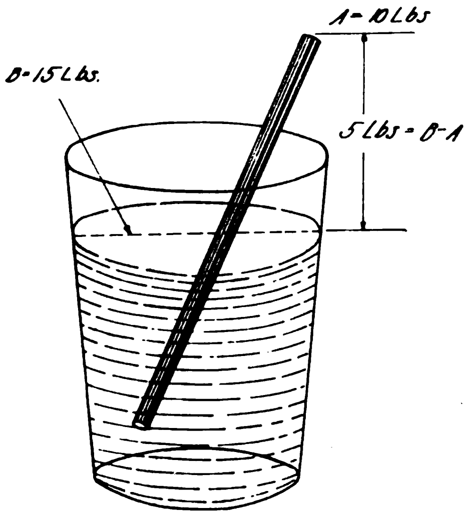

Fig. 168.—Straw analogy.

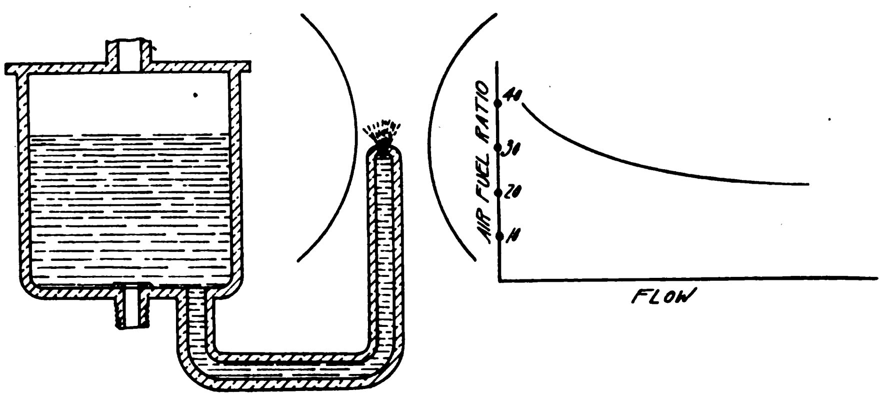

Fig. 169.—Zenith main-jet flow characteristics.

lb. This gives a pressure drop of 15 lb. minus 10 lb. or 5 lb. to force the liquid into the mouth. The greater the suction the greater the quantity of liquid discharged. But if a leak occurs at *C* in the straw, air will enter and reduce the flow rate. This air leak will cause a pressure drop at *C*. Assume that the pressure at *C* is 14 lb., then the pressure causing the liquid to flow will be 15 lb. minus 14 lb. or 1 lb. An increase in the suc-

tion at A will cause only a slight increase in the flow of the fuel because of the air leak at C.

Adaptations to Carburetors. The Zenith combines a simple jet inside of a mixed-flow jet. The simple jet is shown in Fig. 169 and the mixed flow in Fig. 170.

With a simple jet an increase in the mixture flow will cause the fuel to increase at a higher rate than the air, resulting in richness. The curve in Fig. 169 shows this. The mixed flow jet gives a reduction in the richness of the mixture as shown by the curve accompanying Fig. 170.

Now that one jet increases in richness and the other decreases, a constant ratio can be obtained if they are properly proportioned.

The gasoline will be at a level E–E, Fig. 170, in the float chamber A,

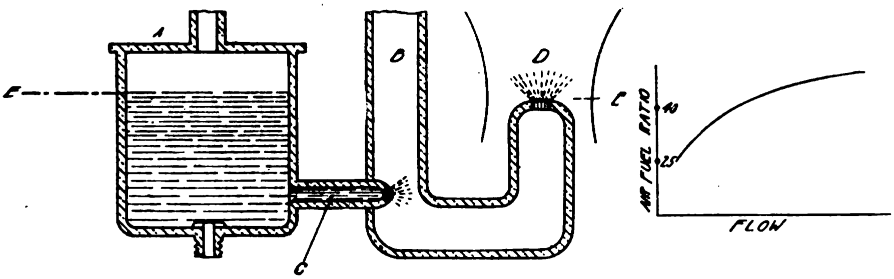

FIG. 170.—Zenith compensator-jet flow characteristics.

the well B and jet D, when no suction occurs on the carburetor. When suction occurs, the fuel will pass out of D and will decline in B. When the suction causes the fuel to flow out of D as fast as it can flow in through the compensator plug C, there will be no fuel in B. If still more suction occurs at the jet, air will pass down B and through the jet D. Note that the quantity of fuel flowing through the compensator plug C is dependent upon the height of the fluid in the float chamber and the area of the plug. The two jets are combined in the carburetor as shown in Fig. 171. The outside jet is known as the cap jet and is not variable in size. The inside jet B is variable in size and is known as the main jet. The compensator plug C is variable in size and supplies the cap jet B with fuel.

The main jet is of sufficient size to supply practically all the fuel at high speed. Then when the speed is reduced the mixture will be too lean. This makes it necessary to add the compensating system, in the form of the cap jet and compensator plug.

Reference to Fig. 172 shows how the two flow curves are added to give the theoretical combined curve. Consider the air-fuel ratio for any flow rate as at A-A.

The main jet is supplying 45 lb. of air to 1 lb. of fuel which is equivalent to 15 lb. of air to .375 lb. of fuel. With 25 lb. of air there will be 1 lb.

of fuel flowing through the compensator plug or with 15 lb. of air, 525 lb. of fuel. Therefore when 15 lb. of air passes through the carburetor the main jet will supply .375 lb., the compensator .625 lb. and the two

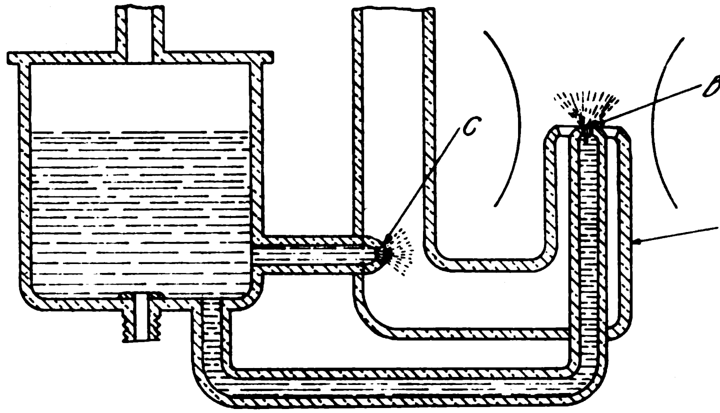

Fig. 171.—Zenith main and compensator jet arranged

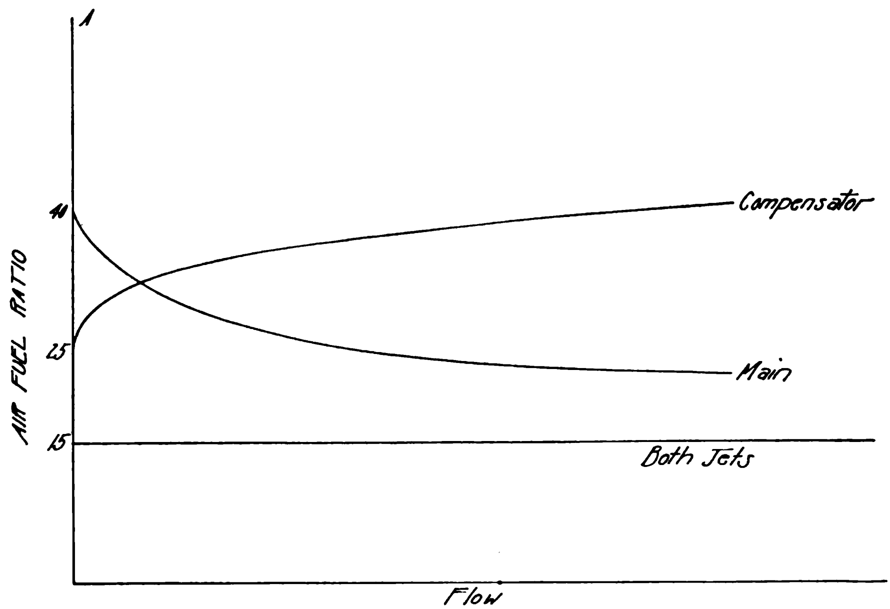

Fig. 172.—Flow characteristic of Zenith carburetor.

combined, 1 lb. of fuel. This means that the air-fuel ratio is 15 to 1. Adding at any point on the curve should give the same ratio.

A choke tube is inserted around the jets to increase the air velocity which increases the fineness of the spray and aids homogeneity.

The idling adjustment is shown in Fig. 173. The liquid stands at a level *H-H*. With the throttle nearly closed the air velocity past the opening *I* is very high, causing considerable pressure drop. This causes the liquid to rise in the tube *A* and into the air line. Tube *B* feeds tube *A* and as the liquid is removed the level in *B* decreases. Tube *B* is fed through an opening at the bottom. As the liquid in *B* is displaced, more is admitted through the bottom, and with a strong suction the

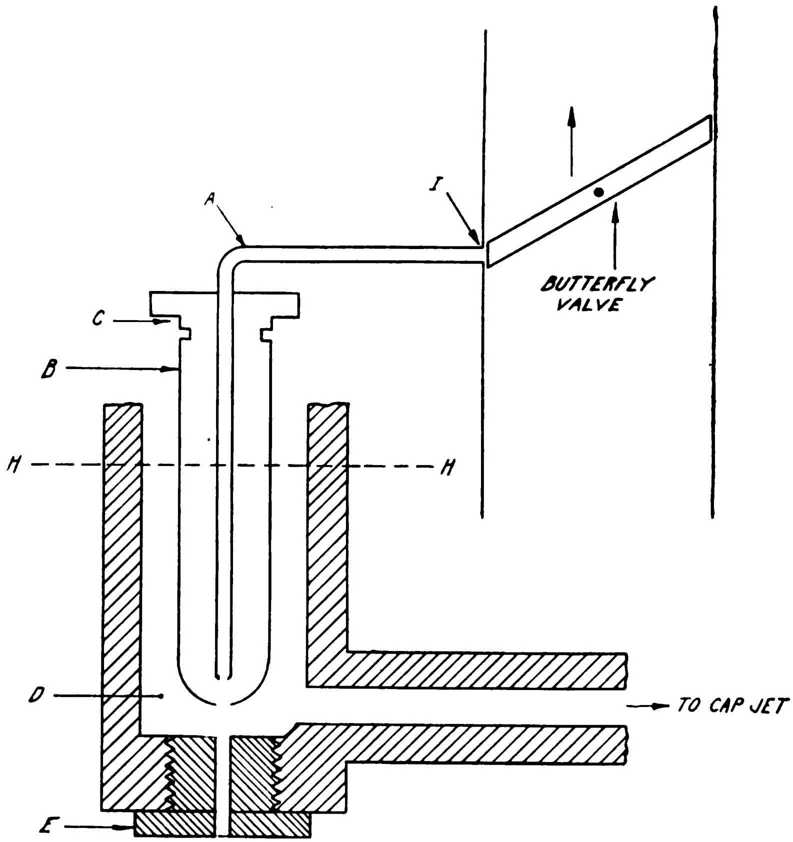

Fig. 173.—Zenith idling well arrangement.

liquid will be displaced as fast as it can be run in through the bottom. At this time air is admitted through the holes *C*. These are four in number and are 1 mm. in diameter. The hole at the bottom of the idling well *D* is variable. The size of the idling well must be varied in conjunction with the position of the throttle. If the valve is opened, more air will be admitted, reducing the richness.

Altitude Adjustment. This is purely float-chamber surface pressure. See Fig. 167. A valve *A* is placed in the air channel connecting the top

of the float chamber with the air passage above the venturi tube. When the valve is opened, the float-chamber surface pressure is reduced. This causes a reduction in the net pressure head, affecting fuel flow.

As an example assume that the float-chamber surface pressure is 15 lb. and that the pressure at the jets is 13 lb. Thus, the pressure head is 15 minus 13 or 2 lb. If the mixture is too rich, the valve *A* can be opened. Assume that this causes a pressure drop in the float chamber to 14.5 lb. Thus the pressure head is 14.5 minus 13 or 1½ lb. The result is a reduction in the rate of flow or a decrease in the mixture richness.

TABLE XIII.—SUMMARY OF ZENITH ADJUSTMENTS.

Idling (200 to 400 r.p.m.).
1. Size of idling well.
Measured in $\frac{1}{100}$ mm. dia.
2. Position of the butterfly valve.
Low speed (400 to 800).
1. Compensator plug.
Measured in $\frac{1}{100}$ mm. dia.
High speed (800 to maximum).
1. Main jet.
Measured in $\frac{1}{100}$ mm. dia.
All speeds.
1. Choke tube.
Measured in mm.

A reduction in size increases the richness of the mixture at all speeds. A small size improves low-speed operation but will reduce the charge weight at high speed. Therefore, use the maximum size consistent with good low-speed operation. To increase the richness of varying jets, use large numbers. To increase the richness by varying the choke tube, use a small number.

Altitude. 1. The position of the altitude valve controls this entirely. The valve is manually operated from the pilot's seat.

The Miller carburetor is also of the mixed-flow type. It has several mixed flow jets arranged in a line with a barrel throttle swinging over them. The throttle varies the size of the air inlet and the number of jets exposed to the air. See Fig. 174. A single jet is shown in cross-section in Fig. 175.

The fuel stands at the level *F-F* when the engine is idle. When suction occurs the fuel is lifted out of the jet *C*. This causes fuel to pass in from the supply line *B* through the orifice *D* to the jet. The level outside of the jet, in the channel *G*, will decrease. With an increase in suction all the fuel will be displaced from *G* and air will enter at *A*, pass down *G*, through the holes *H* in the jet and out of the top.

The hole D in the jet is variable and is numbered in drill sizes, the range being from a No. 78 on the idling side to a No. 50 on the high-speed side of the block.

Idling. The idling jet stands a little higher than the others so that it will be in the path of maximum air velocity when idling. See Fig.

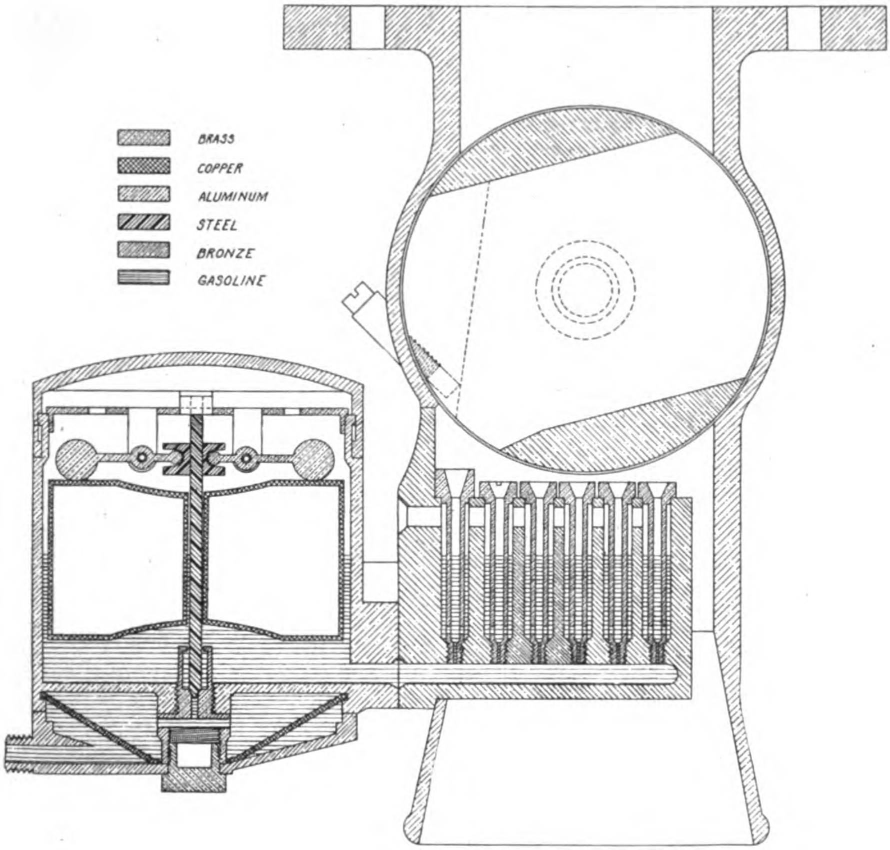

FIG. 174.—Mixed-flow type carburetor.

176. The idling adjustments are the size of the idling jet and the opening of the throttle at A. The set screw for adjusting this is shown in Fig. 174.

Altitude. The compensation for altitude variations is made by restricting the fuel-supply line leading to the distributor block and also by admitting air to the supply line. See Fig. 177.

At sea level the tube B is raised out of the fuel supply line A. At high altitudes the tube is depressed into the channel A. It does two things: first, it obstructs the supply line which reduces the flow rate;

secondly, it admits air down the tube *B* which also reduces the flow. This tube is movable from the pilot's seat.

Homogeneity and low resistance to flow is aided by making the air

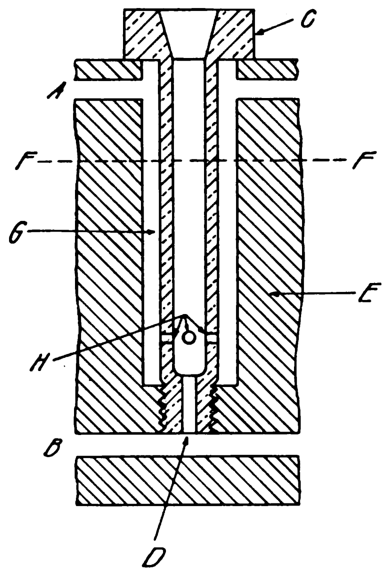

Fig. 175.—Miller carburetor jet.

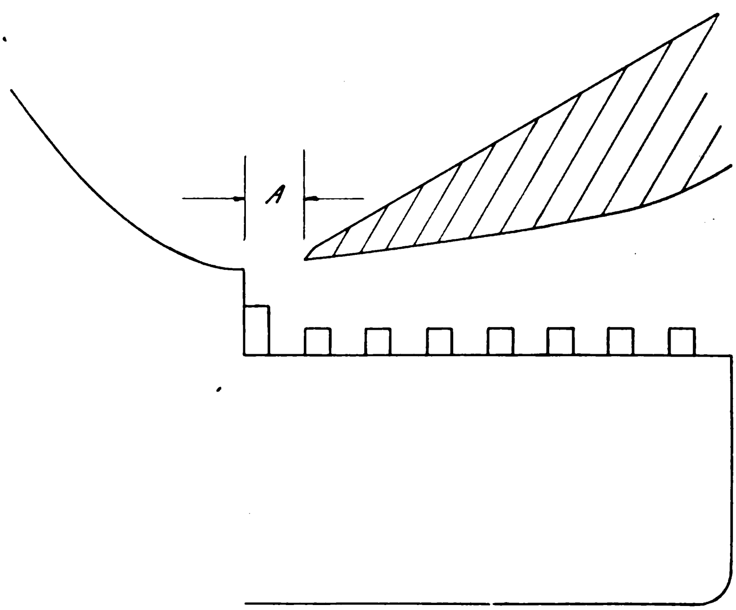

Fig. 176.—Miller rotating barrel throttle.

passage of venturi form. The entrance angle of the air bell *A*, Fig. 178, is 36 degrees and the exit angle *B* through the barrel throttle is 5 degrees.

141. Carburetor Classification by Compensating Devices. The main function of the carburetor is to supply a correct air-fuel ratio. The throttle position is not an indication of the quantity of air flowing, therefore, any carburetor with a throttle-controlled metering pin is

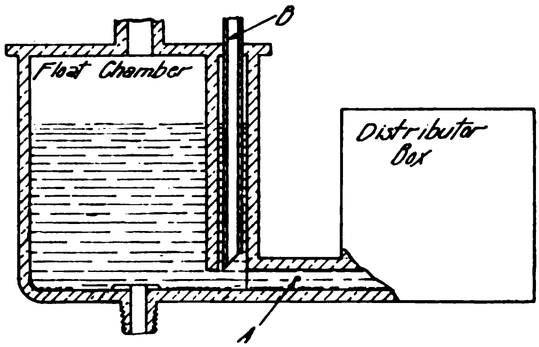

FIG. 177.—Miller altitude adjustment.

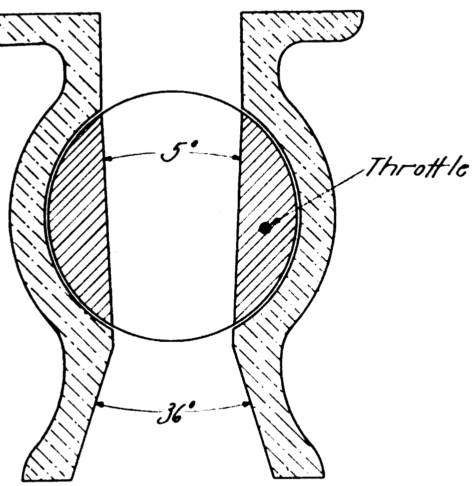

FIG. 178.—Miller barrel throttle angle (exaggerated).

wrong. The metering of the fuel should be independent of all factors except the quantity of air flowing. If the throttle is carefully handled the air-fuel ratio can be kept within the quality range, but if it is not properly handled, the mixture will be either too rich or too lean as shown by Fig. 179.

On pp. 444 to 446 of the Second Annual Report of the National Advisory Committee for Aeronautics, are classified most of the carburetor designs and inventions. Class I are the carburetors which are

probably bad. They include all carburetors without compensating devices.

Class II are the carburetors ranging from bad to fair. These carburetors have throttle-controlled metering pins or in some other way the metering is wrongly related to flow. This class includes the compensators which are not continuous. That is, they work for a short range and then drop out.

Class III includes the devices which are correct in principle and if properly designed will work satisfactorily.

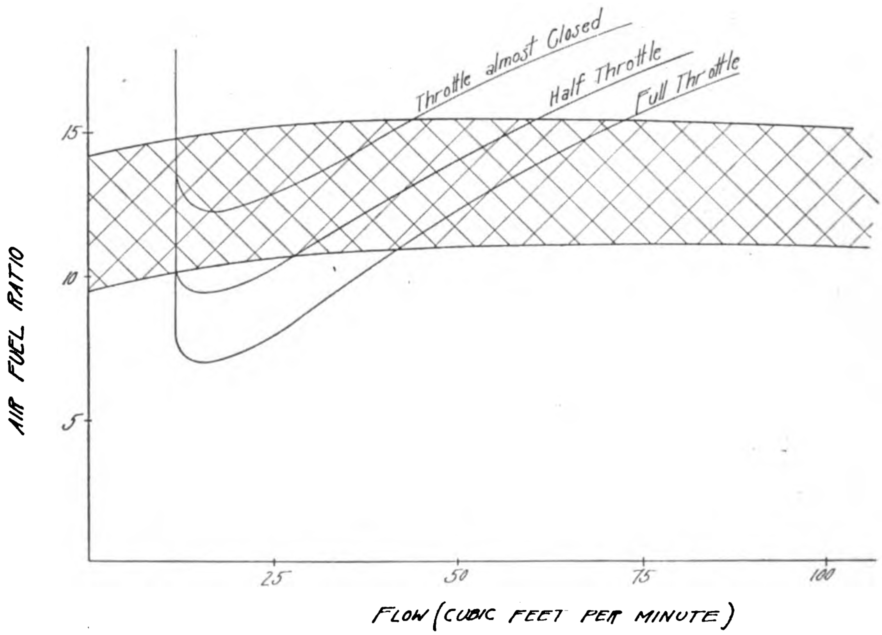

FIG. 179.—Quality curve for a carburetor equipped with throttle controlled metering pin.

142. Carburetor Tests. Reference is again made to the Second Annual Report, pp. 471 to 552, which describes a series of tests run at Columbia University. A Curtiss engine was mounted on a test stand and operated by an electric dynamometer.

Then various carburetors were attached and the quantity of fuel and air supplied measured. From the data, a series of curves were plotted between the air-fuel ratio and quantity of mixture flowing. The tests were made to determine the relative value of various types of compensators and not the value of the carburetor.

The main conclusion is that moving parts are a detriment to carburetion. In every case the carburetors equipped with moving parts showed a variation of the mixture ratio at various times under the same condition.

CHAPTER V

AIRCRAFT ENGINE IGNITION, LECTURES

Introduction

143. Scope of Course. This is a course on airplane engine ignition. It is not a course in general electricity. Neither does it aim to train the student to be an ignition specialist. The ignition course is only one part of the general training in airplane engines. The ignition is one of the most important parts of the engine, and it is essential that the aviation mechanic have a general knowledge of the subject. Only enough theory will be given in this course to enable the student to understand the practical end. It is assumed that the student already has a fundamental knowledge of electricity, and if he has not, it will be necessary for him to study the fundamentals himself. The time alloted for this course does not permit of more than merely touching on the most important points in the fundamentals of electricity and magnetism. For study, "Lessons in Practical Electricity" by Swoope is recommended.

There are three systems of ignition in general use on airplane engines, (1) generator-battery, (2) high-tension magnetos, wound armature type (3) high-tension magnetos, non-wound armature type. The Liberty was the first airplane motor to use a generator-battery system. All others formerly used high-tension magnetos. It is not known that the Liberty will continue to use the battery-coil system exclusively. Another system has been tried out and might be adopted at some future date. The aviation mechanic must have a good general knowledge of all systems.

With the advent of the battery-generator system on the Liberty, new complexities were introduced into airplane engine ignition. The system on the Liberty must supply single and double ignition and an easy means of starting. To do this the Liberty ignition system employs the following:

1. A battery which is a special design, comprising a non-spillable feature. It must supply current when running single ignition.

2. A generator to supply current for double ignition and to charge the battery.

3. A voltage regulator to control the voltage of the generator.

4. A switch to permit of operation on single ignition on either set of plugs or double ignition.

5. Two distributor head assemblies, including coil, breaker mechanism, condenser, and distributor.

It is necessary that the aviation mechanic be familiar with all of these parts to understand the Liberty.

Fundamentals of Electricity

144. Conductors and Insulators. All materials may be divided, with respect to their ability to carry electric current, into two classes:

1. Conductors.
2. Non-conductors or insulators.

It should be understood that there is no such thing as absolute non-conductors. The term is only relative. All materials conduct electricity to a greater or less degree. Those materials which permit the free passage of the electric current are called conductors. Those which offer such a high resistance as to permit only a negligible amount of current to pass are called non-conductors or insulators.

In the following table the substances are arranged in the order of their conductivity, the best conductors being at the top and the best insulators at the bottom of the list.

TABLE XIV.—CONDUCTORS

Good Conductors (Metals and Alloys)	Poor Conductors
Silver	Pure water
Copper	The body
Aluminum	Dry earth
Tungsten	Non-conductors or Insulators
Zinc	Slate
Brass	Porcelain
Platinum	Dry paper
Iron	Rubber
Lead	Shellac
German silver	Mica
Advance metal	Paraffin paper
Nichrome metal	Glass (varies with quality)
Fair Conductors	Dry air
Carbon	
Acid solutions	
Sea water	
Moist earth	

Many of the foregoing materials are used in ignition practice. Silver is used in electrical instruments such as voltmeters and ammeters. Copper is the material most generally used for wiring and for the windings of electrical machines. Lead is used for battery connections; platinum for interrupter points, as it does not oxidize. German silver is an alloy used for rheostats as it has a relatively high resistance. Nichrome is a high resistance alloy which does not deteriorate rapidly. Advance metal is an alloy with a zero temperature coefficient, that is, its resistance

is practically constant regardless of temperature. Alloys which have a relatively high resistance are sometimes classified as resistors. Carbon is used for the brushes of generators and high tension distributors.

Porcelain is used for spark plugs, paper for insulation between the layers of the windings of coils, rubber for high tension leads, shellac for insulating varnish, mica for spark plugs and condensers and paraffin paper for condensers.

The resistance of many of the above materials varies with conditions. For example, most metals have a higher resistance as the temperature is increased. Carbon has the opposite characteristic, that is, its resistance becomes less as the temperature increases. Some kinds of glass although insulators at normal temperatures, if heated become partial conductors. Variations in the quality of certain materials also affect their characteristics as conductors. Mica, which is used for condensers is a good insulator when pure, but sometimes it contains impurities which make it useless for insulating purposes.

145. Electrical Units: Electrical Symbols. The following electrical units are used in ignition practice:

TABLE XV.—ELECTRICAL UNITS

Unit	Definition	Symbol
Volt	Unit of Pressure	E
Ampere	Unit of Current	I
Ohm	Unit of Resistance	R
Watt	Unit of Power	W
Watt-hour	Unit of Energy	W.H.
Henry	Unit of Inductance	
Farad, Microfarad	Units of Capacity	
1 Kilowatt (KW) = 1000 watts		
1 Kilowatt Hour (K.W.Hr.) = 1000 Watt hours		
1 Horsepower = 746 Watts		

Electromotive force e.m.f. called also voltage or difference of potential, is the electrical pressure which causes current to flow. It is not electricity but it is the force or push tending to drive electricity through a circuit. In order to explain more clearly the meaning of electromotive force, a comparison may be drawn with the action of water flowing through a pipe. If there are two tanks containing water at different levels, connected by a pipe, water will flow from the tank of higher level to the one of lower level. The flow of water is caused by the difference in head or pressure between the two tanks. In the same way if there are two points in an electrical circuit, one of which is at a higher potential or electrical pressure than the other, current will flow in the circuit due to the difference in potential between the two points. It is possible to have a difference of potential or voltage existing without current

flowing just as it is possible to have water pressure without water flowing. For example, in the case mentioned above, if there were a closed valve between the tanks there would be pressure at the valve but no water would flow. Similarly, if we have a battery with the terminals not connected by a conductor, there will be a difference of potential or pressure between the terminals although no current will flow.

The current in an electrical circuit is the rate of flow of electricity. An ampere is a certain quantity of electricity flowing per second, similar

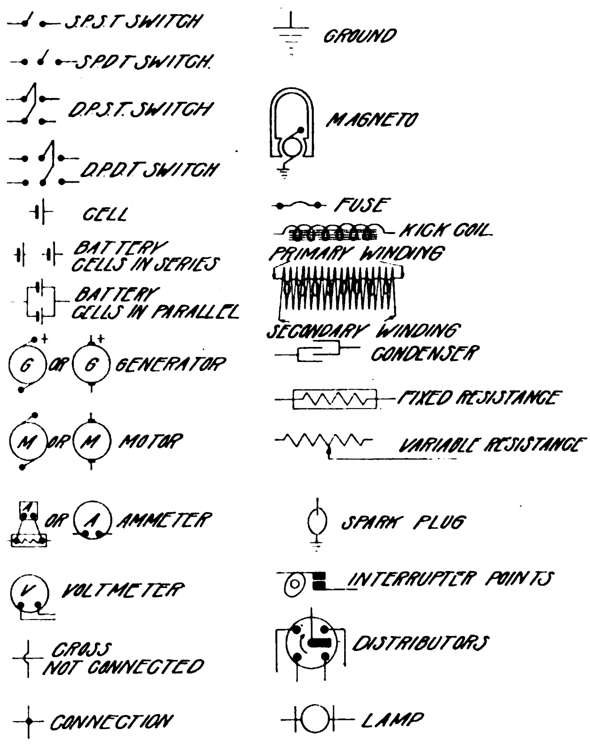

FIG. 180.—Conventional electrical symbols.

to gallons per second in a water system. It should be clearly understood that the ampere is not the unit of quantity of electricity, but of rate of flow or quantity per second.

Resistance may be defined as that property of a substance by which it opposes the flow of the electric current. For example, carbon which is considered only a fair conductor has a higher resistance than copper which is a good conductor. Resistance in an electrical circuit may be likened to the resistance offered by a pipe to the flow of water due to bends, joints and the character of the inside surface of the pipe.

The symbols shown in Fig. 180 are most commonly used in diagrams of electrical circuits.

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146. Laws of a Direct-current Circuit. Laws of resistance:

(1) The resistance of a conductor is directly proportional to its length. For example, if 1,000 ft. of No. 10 wire has a resistance of 1 ohm, 2000 ft. will have a resistance of 2 ohms.

(2) The resistance of a conductor is inversely proportional to its cross-sectional area. In the case of a round wire it is inversely proportional to the square of the diameter.

The area of cross section of a wire is usually expressed in circular mils. The area in circular mils of a round wire is equal to the diameter in mils squared. One mil equals .001 in. Hence a wire which has a diameter of $\frac{1}{10}$ in. or 100 mils will have a cross-sectional area of 10,000 cir. mils. For example, No. 10 wire B. & S. gage has a diameter of $\frac{1}{10}$ in. or 100 mils and a resistance of 1 ohm per 1,000 ft. No. 16 wire has a diameter of $\frac{1}{20}$ in. or 50 mils. The cross-sectional area of No. 16 wire is 2500 cir. mils while that of No. 10 wire is 10,000 cir. mils. Therefore the resistance of No. 16 is four times that of No. 10 or 4 ohms per 1000 ft.

(3) The resistance of a conductor of given length and cross-sectional area depends upon the material of which it is made. For example, the resistance of 1,000 ft. of copper wire $\frac{1}{10}$ in. in diameter (No. 10 B. & S. gage) is approximately 1 ohm, while the resistance of 1,000 ft. of iron wire $\frac{1}{10}$ in. in diameter is about 6.3 ohms.

These three laws may be summarized in the following formula by which the resistance of any piece of material can be calculated:

$$R = K\frac{l}{d^2}$$

R = the resistance in ohms.
K = a constant for the material.
l = the length in ft.
d = the diameter in mils.
K for copper is 10.5

The wire gage most commonly used in this country is the B. & S. gage (Brown and Sharpe Manufacturing Company).

The approximate resistance and cross-sectional area of any wire in the foregoing table can be readily calculated from memory when the table is not available if the following facts are remembered: No. 10 wire has a resistance of approximately 1 ohm per 1,000 ft. and a cross-sectional area of 10,000 cir. mils. Starting from No. 10 wire and going down the table, every third size has approximately twice the resistance and one-half the cross-sectional area. Going up the table from No. 10 every third size has approximately one-half the resistance and twice the cross-sectional area.

For example, No. 13 wire, which is the third size below No. 10, has a

resistance of approximately 2 ohms per 1,000 ft. and a cross-sectional area of approximately 5,000 cir. mils. No. 16 wire, which is the third size below No. 13, has a resistance of approximately 4 ohms per 1,000 ft. and a cross-sectional area of approximately 2,500 cir. mils.

Ohm's law: Ohm's law may be stated as follows:

The current in any circuit is equal to the pressure divided by the resistance.

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}$$

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

$$I = \frac{E}{R}$$

Water analogy: An electrical circuit may be compared to a hydraulic system in which a pump delivers water to a system of piping. There will be a certain pressure at the pump expressed in pounds per square inch. This corresponds to the electrical pressure or volts at the generator or other source of supply in the electrical circuit.

The piping in the water system will offer a certain resistance to the flow of water, that resistance depending on the length and diameter of the pipe and the material of which it is made. In the same way the conductors in the electrical circuit offer a certain resistance to the flow of electricity or current and the value of this resistance is expressed in ohms.

In the water system there will be a certain flow of water expressed in gallons or cubic feet per second. This corresponds to the flow of current or amperes in the electrical circuit.

Carrying the comparison between the two systems further, if the pressure or pounds per square inch at the pump in the water system is increased, the number of gallons per minute flowing will be increased. Referring to Ohm's law it is evident that if the pressure or volts is increased, the current will be increased.

In the water system if the resistance of the piping is increased by using smaller pipes or greater lengths of pipe, the flow of water will be decreased. Similarly, in the electrical system if we increase the resistance of the circuit, as for example, by using smaller wire or greater lengths of wire, the current will be less.

Power and work: The power in an electrical circuit is equal to the volts multiplied by the amperes and is expressed in watts.

$$\text{Power} = \text{Watts} = \text{Volts} \times \text{Amperes}$$
$$W = E \times I$$
$$W = IR \times I = I^2R$$

The work done in an electrical circuit is equal to the volts multiplied by the amperes multiplied by the time the current is flowing.

$$\begin{aligned} \text{Work} &= \text{Volts} \times \text{Amperes} \times \text{Hours.} \\ &= \text{Watts} \times \text{Hours.} \\ &= \text{Watt-hours.} \end{aligned}$$

The unit of work is the watt-hour which is the work done when one ampere flows under a pressure of one volt for one hour. A larger unit which is more generally used is the kilowatt-hour.

$$1{,}000 \text{ watt-hours} = 1 \text{ Kilowatt hr.} = 1 \text{ K.W. Hr.}$$

The following table may help to form a clear understanding of the units of electricity.

TABLE XVII.—UNITS OF ELECTRICITY

Electrical system	Water system
Pressure = Volts = E	Pressure = lb. per sq. in.
Resistance = Ohms = R	Resistance
Current = Amperes = I	Rate of flow = gal. per sec.
Power = Watts = W	Power = ft. lb. per min.
or Kilowatts = K.W.	or Horsepower = H.P.
Work = Watt-hours = W. Hr.	Work = ft. lb.
or Kilowatt-hours = K.W. Hr.	or Horsepower hours = H.P. Hr.

147. Application of Laws of Direct-current Circuit; Water Analogy. CASE I.

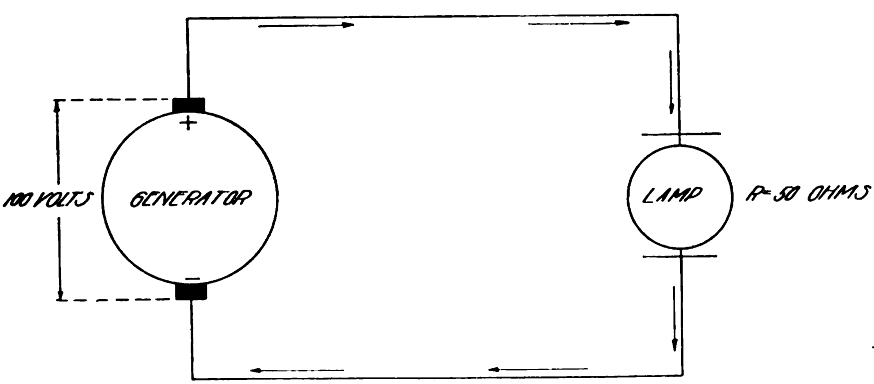

Fig. 181.—Simple Electrical Circuit.

Fig. 181 shows a simple electrical circuit consisting of a generator connected to a lamp. The voltage or pressure at the generator terminals is 100 volts. The resistance of the lamp is 50 ohms. The resistance of

the leads may be neglected, hence the voltage across the lamp is 100 volts. The current flowing in the circuit can be calculated from Ohm's law.

$$\text{Circuit current} = \frac{\text{Volts}}{\text{Ohms}} \text{ or } I = \frac{E}{R}$$

$$I = \frac{100}{50} = 2 \text{ amperes.}$$

The power taken by this circuit is

$$W = E \times I = 100 \times 2 = 200 \text{ watts.}$$

The foregoing case may be compared to a hydraulic system such as is shown in Fig. 182 composed of a pump supplying water to a water

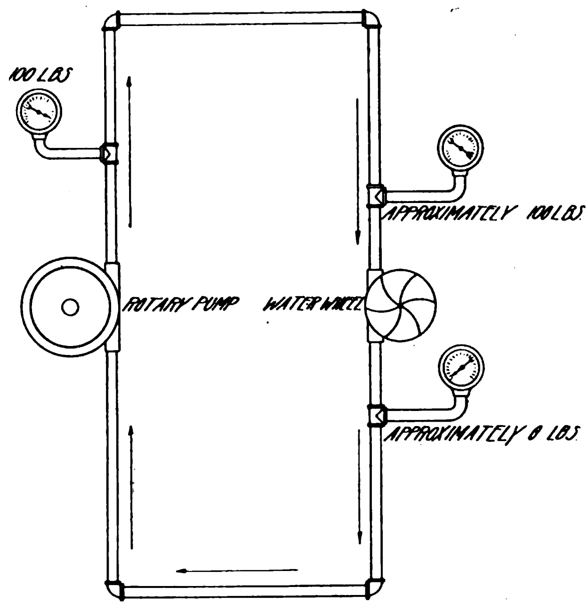

FIG. 182.—Hydraulic analogy to a simple electrical circuit.

wheel or turbine. The water wheel offers a certain resistance which must be overcome by the pressure of the pump in order to cause water to flow in the system. If the pressure at the pump is increased the flow of water through the water wheel will be increased. The power delivered to the water wheel will also be increased since the power is also proportional to both the pressure and the flow of water. The pressure at the wheel is approximately the same as at the pump, neglecting the small pressure drop in the pipes.

Case II.

In the case shown in Fig. 183, two lamps are connected in series,

that is, the total current in the circuit passes through each lamp in turn. Since the resistance of the leads may be neglected, the voltage across the two lamps in series is 100 volts.

If two or more resistances are connected in series, the total resistance of the circuit is equal to the sum of the individual resistances.

Or if R = the total resistance of the circuit.
R_1 = the first resistance.
R_2 = the second resistance.
R_3 = the third resistance.

then $R = R_1 + R_2 + R_3$.
In this case:

$$R = R_1 + R_2 = 40 + 60 = 100 \text{ ohms.}$$

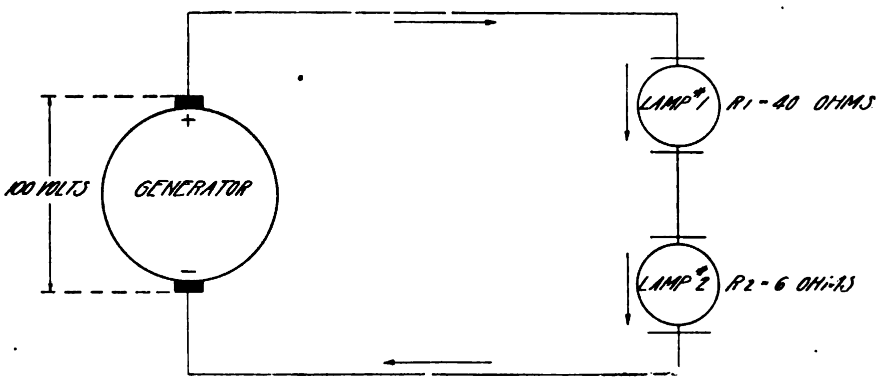

FIG. 183.—Series circuit.

Therefore:

$$\text{Circuit current} = I = \frac{E}{R} = \frac{100}{100} = 1 \text{ ampere.}$$

Voltage across lamp No. 1 = 1 ampere × 40 ohms
= 40 volts
Voltage across lamp No. 2 = 1 ampere × 60 ohms
= 60 volts

Case II is analogous to a hydraulic system such as is shown in Fig. 184 where two water wheels are connected in series, that is the total water delivered by the pump passes through each wheel in turn. If the two wheels are of the same size, they will offer approximately twice as much resistance to the flow of water as one wheel, and the flow of water will therefore be approximately half as much. Neglecting the small pressure drop in the pipes the pressure across both wheels will be the pressure at the pump and the pressure drop in each wheel will be approximately one-half the total pressure. In other words if there is 100 lbs. pressure at the pump there will be approximately 50 lbs. pressure drop

in each wheel. Since both the pressure and the flow of water in each wheel is less than in the first case, the power delivered to each wheel will be less.

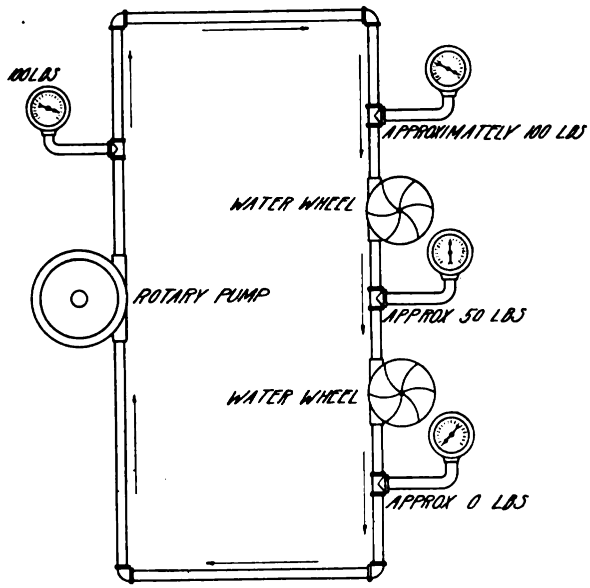

FIG. 184.—Hydraulic analogy to a series circuit.

Case III.

In the case shown in Fig. 185 two equal resistances are connected in parallel, that is, the total current divides equally between the two

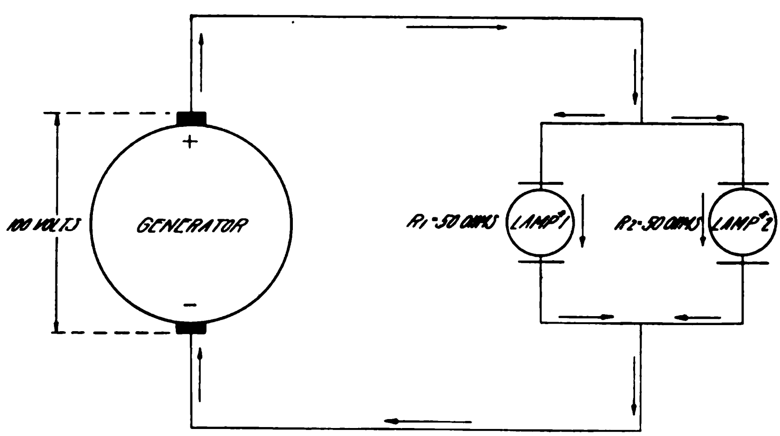

FIG. 185.—Parallel circuit, equal resistances.

resistances. Again neglecting the resistance of the leads, the voltage across each lamp is 100 volts.

If two or more equal resistances are connected in parallel, the total resistance of the circuit is equal to the value of a single resistance, divided by the number of resistances connected in parallel.

$$R = \frac{R_1}{n}.$$

Where n = the number of resistances connected in parallel.
R = the value of one resistance.

$$R = \frac{R_1}{N} = \frac{50}{2} = 25 \text{ ohms.}$$

Therefore:

$$\text{Circuit current} = I = \frac{E}{R} = \frac{100}{25} = 4 \text{ amperes.}$$

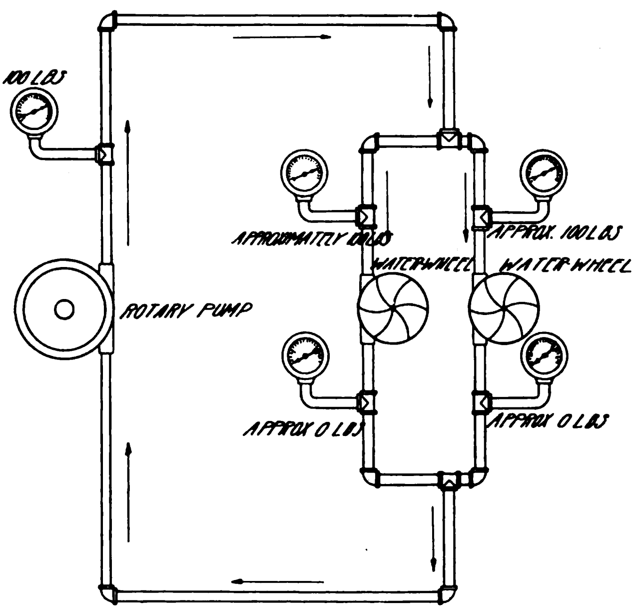

Fig. 186.—Hydraulic analogy to a parallel circuit with equal resistances.

The power taken by this circuit is

$$W = E \times I = 100 \times 4 = 400 \text{ watts.}$$

$$\text{Current taken by lamp No. 1} = \frac{100}{50} = 2 \text{ amperes.}$$

$$\text{Current taken by lamp No. 2} = \frac{100}{50} = 2 \text{ amperes.}$$

Hence total circuit current = 2 + 2 = 4 amperes.

Checking previous calculation.

Case III is analogous to a hydraulic system, such as is shown in Fig. 186 where two water wheels of the same size are operated in parallel, that is, the total flow of water is divided between the two wheels.

In this case the flow of water to each wheel will be the same as for the one wheel in Case I. Therefore the total flow will be twice as much as in Case I. The pressure at each wheel will be approximately the same as at the pumps and the pressure drop in each wheel will be approximately the total pressure of the pump. Since the pressure and flow to each wheel is the same as for the one wheel in Case I, the total power delivered by the pump will be twice as much as in Case I.

Case IV.

In the case shown in Fig. 187, two unequal resistances are connected in parallel. The voltage across each lamp is 100 volts.

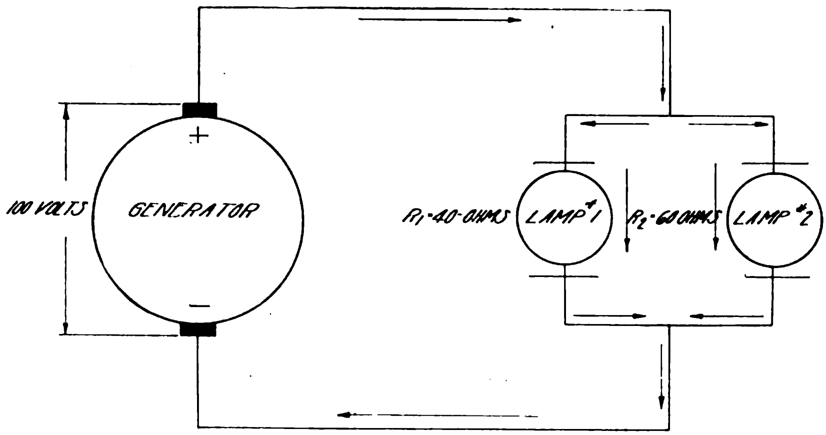

FIG. 187.—Parallel circuit, unequal resistances.

If two or more unequal resistances are connected in parallel, the reciprocal of the total resistance is equal to the sum of the reciprocals of the individual resistances.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}.$$

In the foregoing case,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{40} + \frac{1}{60}.$$

$$\frac{I}{R} = \frac{3}{120} + \frac{2}{120} + \frac{5}{120} = \frac{1}{24}.$$

$$R = 24 \text{ ohms.}$$

$$I = \frac{100}{24} = 4.17 \text{ amperes.}$$

The power taken by this circuit is

$$W = E \times I = 100 \times 4.17 = 417 \text{ watts.}$$

The current taken by lamp No. 1. $= \frac{100}{40} = 2.5$ amperes.

The current taken by lamp No. 2. $= \frac{100}{60} = 1.67$ amperes. Hence total circuit current $= 2.5 + 1.67 = 4.17$ amperes, checking previous calculation.

Case IV is analogous to a hydraulic system such as is shown in Fig. 187 where two water wheels of unequal size are connected in parallel. The flow to each wheel will be the same as if it were used alone. Therefore

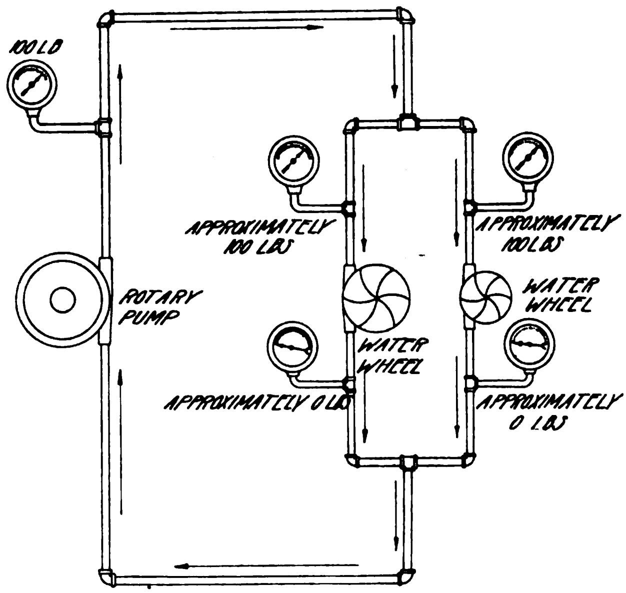

FIG. 188.—Hydraulic analogy to a parallel circuit with unequal resistances.

the total quantity of water flowing from the pump will be the sum of the quantities taken by the two wheels. The total power delivered by the pump will be the power taken by the first wheel plus the power taken by the second wheel.

Fundamentals of Magnetism

148. Magnets and Magnetic Flux. The name magnet was first applied to a mineral which in its natural state, possessed the property of attracting pieces of iron or steel. If a natural magnet is rubbed against a piece of iron or steel it imparts its magnetic properties to the iron or steel, hence the latter becomes a magnet. Another property of a magnet is that if suspended so that it is free to rotate in a horizontal plane, it will take a position pointing approximately north and south.

Magnets may be classified as:

1. Natural.
2. Artificial.

a. Permanent—steel magnet.
b. Temporary.
  1. Iron under the influence of a permanent magnet.
  2. Electromagnet.

The ends of a magnet are called its poles. The pole which points turned toward the north geographic pole of the earth is called the north pole, usually designated by the letter N, while the other end is called the south pole, usually designated by the letter S.

If a magnet, such as a compass needle is suspended so that it is free to rotate, and the south end of a bar magnet is brought near the north end of the suspended magnet, the two will be found to attract each other. On the other hand if the south pole of one is brought near the south pole of the other, the two will repel each other. Two north poles will behave in the same manner as two south poles. Hence, like magnetic poles repel each other but unlike magnetic poles attract each other.

If a piece of steel is rubbed with only one pole of a magnet, it will have a north and a south pole. If a magnet is broken into pieces each

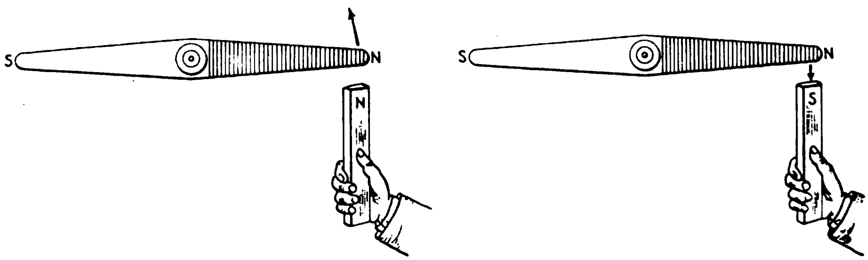

Fig. 189.—Magnetic attraction and repulsion.

piece will be a magnet and will have a north and a south pole. It is impossible to produce a magnet with only one pole.

A magnetic substance is one which is attracted by a magnet. The most common magnetic substances are iron and steel. There are a few other substances, such as cobalt and nickel, which are attracted by a magnet, but only to a slight degree, so that for practical purposes, all substances except iron and steel may be regarded as non-magnetic.

The force exerted by a magnet to attract or repel another magnet or to attract pieces of iron is called magnetic force. The space surrounding a magnet through which its influence extends is called the magnetic field of the magnet. At every point in the field the magnetic force has a definite strength and direction. To show the direction of this force, if we take a compass needle and move it around a magnet its direction will vary according to its location in the magnetic field. The arrows in Fig. 190 indicate in a general way the direction in which the north pole of the compass will point.

As the compass needle always points in the direction of the magnetic force, the lines in Fig. 190 represent the direction of the magnetic force about the magnet and are called magnetic lines of force. It is assumed that the lines of force come out of the north pole of a magnet, pass through the surrounding medium, enter the south pole and return to the north pole through the magnet. Every line of magnetic force must have a complete circuit, that is it must have a closed path.

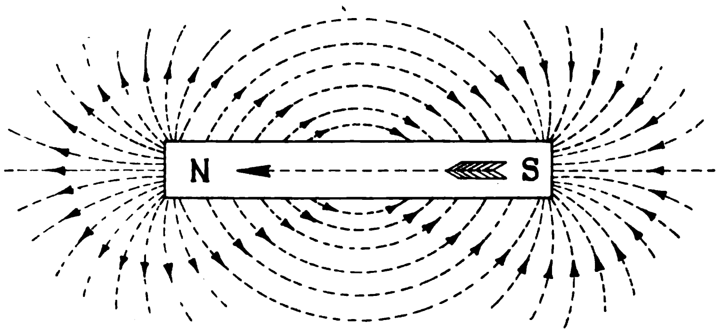

FIG. 190.—Magnetic lines of force about a bar magnet.

A practical method of demonstrating the presence of a magnetic field around a magnet is to lay a bar magnet on a table and place a piece of cardboard over it. Then sift iron filings in a thin layer over the cardboard, tapping the cardboard lightly several times. The iron filings will arrange themselves according to the direction of the lines of force about the magnet as indicated in Fig. 191.

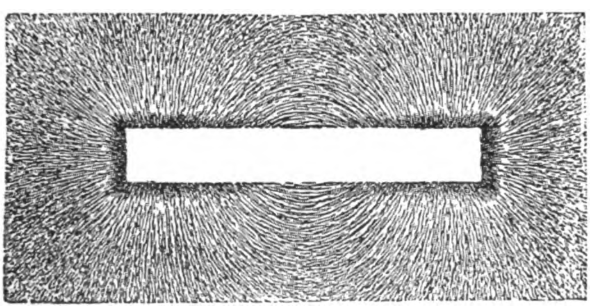

FIG. 191.—Magnetic field of a bar magnet as shown by iron filings.

The term *lines of force* is also used to denote the strength of a magnetic field, that is, a magnetic field is said to have a strength of so many lines of force. For example, a field of 10,000 lines of force would have twice the magnetic strength of a field of 5,000 lines of force. The total number of lines of force or total quantity of magnetism is called the *flux.*

149. Electromagnetism. If a compass needle is held above a wire carrying an electric current, it will be deflected so that it points at right angles to the wire. If held below the wire it will point in the opposite direction as shown in Fig. 192.

Since a compass needle is only affected by a magnetic field, this experiment proves that if a current flows in a conductor, there is a mag-

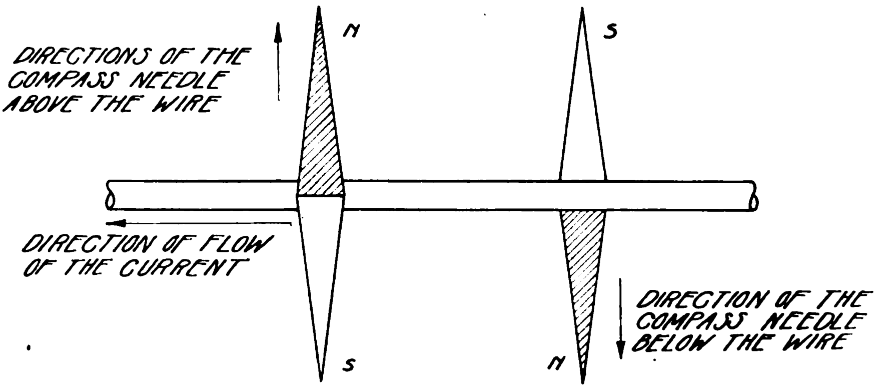

Fig. 192.—Demonstration by means of a compass of the presence of a magnetic field about a wire carrying current.

netic field around the conductor. Further investigation would show that the direction of the lines of force around the conductor are as shown in Fig. 193.

Each line is a complete closed circle around the conductor. If the direction of the current through the wire were reversed, the direction of the lines of force would be reversed. The direction of the lines of

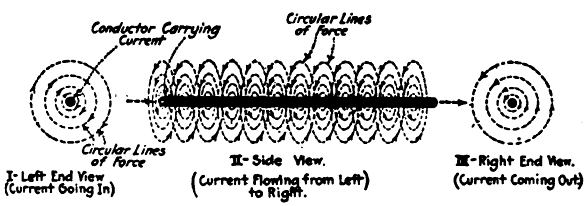

Fig. 193.—Lines of magnetic force about a conductor carrying current.

force around a conductor may be determined from the following rule: If the conductor is grasped with the right hand with the thumb pointing in the direction of flow of the current, then the direction of the fingers represent the direction of the lines of force, as illustrated in Fig. 194.

If a conductor is wound in the form of a helix or solenoid, and current is passed through the conductor, the lines of force or flux produced by the current will have the direction indicated by the arrows in Fig. 195. The solenoid thus has polarity like a bar magnet.

If an iron core is placed in the solenoid, the magnetic properties of the solenoid become much more pronounced. This is because iron is a much better conductor of magnetism than air, that is, it offers much less

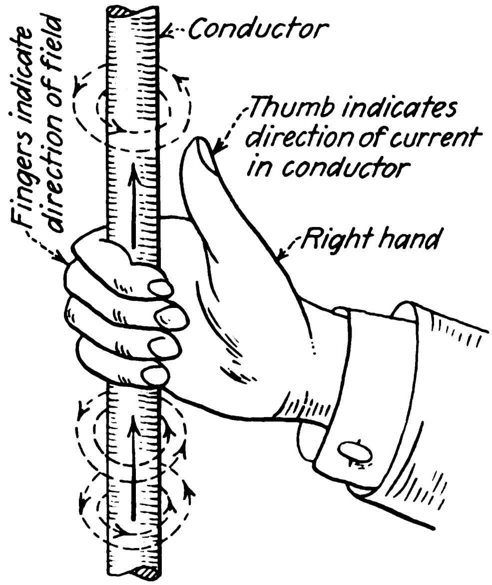

FIG. 194.—Right-hand rule for determining the direction of the lines of force about a conductor carrying current.

resistance to the flow of lines of force. Therefore there will be a great many lines of force through the iron core and the solenoid becomes a stronger magnet. A solenoid with an iron core is called an electromagnet.

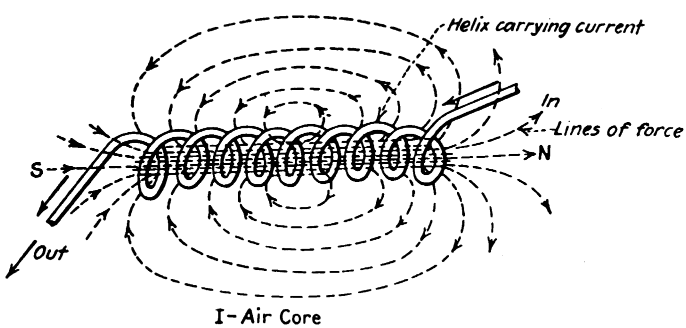

FIG. 195.—Lines of force about a helix or solenoid carrying current.

The strength of an electromagnet depends upon:

1. The number of turns in the winding. The greater the number of turns, the greater the strength of the magnet.

2. The current in the winding. The greater the current the greater the strength of the magnet.

3. The quantity and kind of material composing the core. If the core is of iron, the strength of the magnet will be greater than if it is of some non-magnetic material. If the core is of large cross-sectional area and short length the magnet will be stronger than if it is of small cross-sectional area and long length.

150. Magnetic Circuit. As stated previously, lines of magnetic force must always traverse a closed path or complete circuit. This path is called the magnetic circuit. In practice, it is composed mainly of iron or steel but may be partly air or other non-magnetic material.

The force which causes lines of force or flux to flow in a magnetic circuit is called magnetomotive force. It is equal to the current in amperes multiplied by the number of turns of wire. This product is called ampere turns.

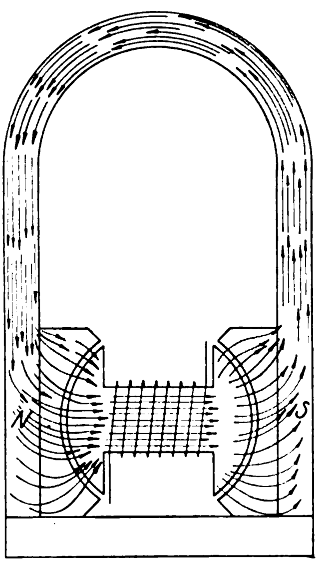

FIG. 196.—Magnetic circuit of a magneto.

Reluctance is that property of a material by which it tends to resist the flow of magnetic lines of force. For example, iron has a much lower reluctance than air, that is, it permits the passage of lines of force through it more readily than air. In practically all substances except iron and steel, the reluctance is the same and very much higher than for iron and steel.

The law of the magnetic circuit may be stated as follows: The flux is equal to the magnetomotive force divided by the reluctance.

$$\text{Flux} = \frac{\text{Magnetomotive force}}{\text{Reluctance}}$$

The law of the magnetic circuit plays an important part in ignition work. For example, in a magneto or generator, the air gap between the armature and pole pieces is part of the magnetic circuit. If this gap is changed from its normal value by even a small amount the reluctance of the magnetic circuit may be altered sufficiently to cause the machine to function badly. The adjustment of the Liberty voltage regulator depends upon the variation of the air gap in the magnetic circuit.

Not all magnetic substances can become permanent magnets. Soft iron and soft mild steel, though they can be temporarily highly magnetized, lose most of their magnetism as soon as the magnetizing force is removed. For example the soft iron core of an electromagnet will lose practically all of its magnetism when the current in the winding is turned off. Hard steel, however, will retain most of its magnetism. This property of retaining magnetism is called retentivity. The magnetism which

remains in a piece of iron or steel after the magnetizing force has been removed is called residual magnetism. The retentivity of hard steel is large, while that of soft iron is small.

Demonstrations during Study Period.

(*a*) Characteristics of wire conductors: Current is passed through three wires connected in series with each other and with an ammeter as shown in Fig. 197. The wires are of the same length and diameter, but of different materials, namely, copper, iron and German silver. A small current, about 6 amperes to start with, should be passed through the three wires and the voltage drop across each wire noted. The relative values will be approximately, copper .05 volts, iron, .31 volts and German silver, .61 volts. It should be noted that if wires of about No. 16 size are used, no appreciable heating of the copper will occur, while the iron and German silver will be warm. The higher voltage drop in the iron and German

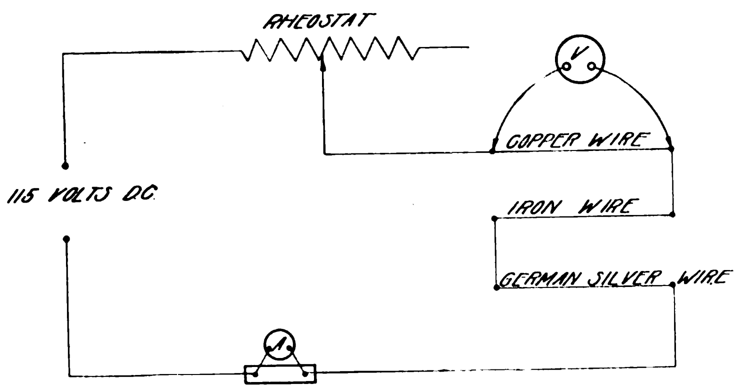

FIG. 197.—Connections for demonstrating the characteristics of wire conductors.

silver shows that they have a higher resistance than the copper. As a result of the higher resistance more power is consumed in the iron and German silver than in the copper which causes the greater heating effect. The current should then be increased through several steps and the increased voltage drop and heating noted. At higher current values the iron will become hotter and show a higher voltage drop than the German silver. This is because iron has a higher temperature coefficient than German silver, that is, its resistance increases more rapidly with increase in temperature than the German silver. If the current is raised to a high enough value the iron will eventually melt before the copper or German silver.

(*b*) Connections should be made as shown in Figs. 2, 4 and 6, in "Fundamentals of Electricity," for one lamp, two in series, and two in parallel, and Cases I, II & III demonstrated.

(*c*) A current of any convenient value should be passed through a

wire and a compass needle held first above the wire and then below it, demonstrating the direction of the magnetic field produced by the current.

(*d*) Demonstration with permanent magnet with winding: A permanent horse-shoe magnet with a winding on it should be used in this demonstration. It should be suspended by the hook of a spring balance, so that any pull exerted on the keeper of the magnet will be registered on the spring balance. With no current in the winding, the number of pounds required to pull the keeper off the magnet should be noted. With a small current in the winding, the demonstration should be repeated noting the increased pull required due to the increase in flux caused by the current. A larger current should then be passed through the winding and the increased pull again noted. The direction of the current should then be reversed and the current increased until the keeper falls off, showing that the flux produced by the current being opposite to the permanent magnetism of the magnet, demagnetizes it.

(*e*) Students should be required to copy the chart of conventional signs and symbols.

(*f*) Students should be required to copy the wire table.

Direct-current Generators and Methods of Voltage Regulation

151. Voltage Generation. Discussion of the two methods of generating voltage and practical applications. There are two distinct methods of voltage generation, namely, (*a*) a stationary magnetic field and a moving conductor and (*b*), a stationary coil of wire and a magnetic field varying in intensity or in both intensity and direction. Practically all direct-current generators operate upon the first principle. If a conductor is moved in a magnetic field so as to cut lines of force a voltage is generated in it. In practice instead of using single conductors, loops or coils of wire are employed, the voltage being generated in the coil side. A generator employing a single loop, commonly known as a simple generator is shown in the illustration (Fig. 198). The arrows show the direction in which current would flow were the brushes connected.

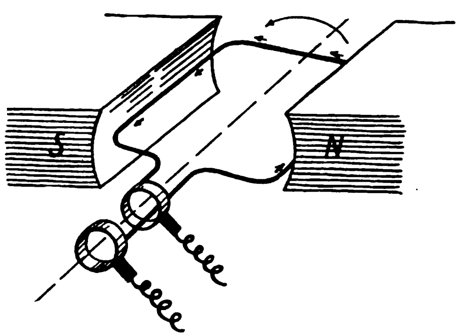

FIG. 198.—Simple alternating-current generator.

Magnitude and Direction of Voltage for Various Coil Positions. The magnitude of the voltage generated, when a conductor cuts lines of force, is proportional to the number of lines of force cut per unit of time.

The direction of the voltage generated depends upon the direction in which the conductor cuts the lines of force and the direction of the magnetic field.

Thus, referring to Fig. 198, when the coil is being revolved at a constant speed no voltage is generated in the coil side while the coil is in the vertical position. This is due to the fact that the coil sides are moving parallel to the magnetic field and cut no lines of force. From this vertical position through one quarter of a revolution, the rate at which the coil sides cut lines of force constantly increases and reaches a maximum when the coil is in the horizontal position. During the next quarter revolution the rate at which the lines of force are being cut constantly decreases. Since the magnitude of the generated voltage is proportional to the rate at which lines of force are cut, the voltage changes in magnitude in the

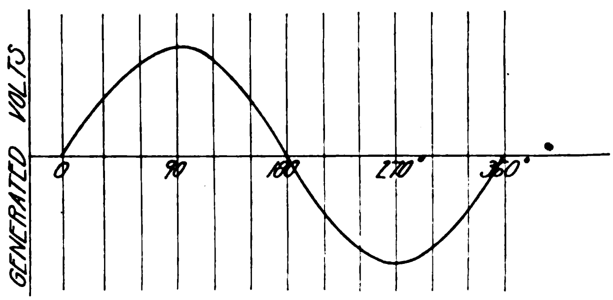

Fig. 199.—Voltage wave of a simple alternating-current generator.

same manner. During the next half revolution we have the same variation in magnitude of the generated voltage. Since the direction in which the coil sides cut lines of force changes every half revolution, that is each time the coil is in a vertical position, the direction of the generated voltage also reverses at these points. It is to be noted that no matter what the direction of the voltage in the coil, the voltage generated in the two coil sides are always in series around the loop. A typical wave of alternating voltage is shown in Fig. 199.

In this illustration 90 degrees represents the horizontal coil position shown in Fig. 198, and 270 degrees represents its position a half revolution later.

Factors Affecting Magnitude of Voltage Generated. As stated above, the magnitude of the voltage generated is proportional to the number of lines of force cut in a unit of time. In the commercial generator electromagnets are employed, instead of permanent magnets, to supply the magnetic field. Thus we have the following factors affecting the magnitude of the voltage generated: (*a*) the speed at which the coil is revolved; the higher the speed the greater becomes the generated voltage and (*b*) the strength of the magnetic field; this depends upon the number

of turns of wire in the field winding and the current in this winding. The number of turns is taken care of in the design and the current can usually be varied over a wide range. The voltage at constant speed will increase with increased current and increased turns.

Induction coils, transformers and most magnetos operate upon the second principle of voltage generation. If the number of lines of force passing through a coil of wire is changed, a voltage is generated in the coil. Thus in Fig. 200, when current flows through the exciting coil *b*, the bar of iron becomes magnetized, lines of force coming out at the left-hand end and going back into the bar at the right-hand end. The complete lines of force are not shown in the illustration but most of them will pass back on the outside of the coil *a*. Now, if the current in coil *b* is suddenly changed by means of the variable resistance, the number of lines of force coming out of the bar of iron will also change. This is

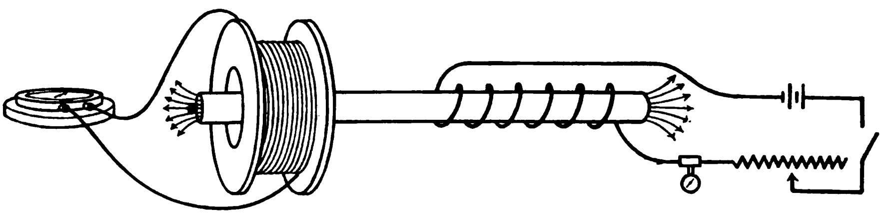

FIG. 200.—Second method of voltage generation.

due to the fact that the strength of an electromagnet depends upon the current flowing in the winding. As soon as the current in coil *b* is changed, the voltmeter needle will be deflected, showing that a voltage was generated in coil *a*. It will be found that the needle will be deflected in one direction when the current in coil *b* is increased and in the opposite direction when this current is decreased. The same effect will be produced if the switch is opened and closed.

It will also be found that the magnitude of the voltage generated, as shown by the amount of deflection obtained on the voltmeter, depends upon two factors. The first of these is the speed at which the field collapses, and the second is the strength of the field before collapse. Thus, if the current in coil *b* is set so that the ammeter reads just one ampere and then the switch is opened rapidly, the voltmeter will show a large deflection. On the other hand if, with the same current in coil *b*, the switch is opened slowly, a very much smaller deflection of the voltmeter needle will result. Again, if the switch is opened as rapidly as possible when the current in coil *b* is one ampere, there will occur a much smaller deflection than if the switch were opened at the same speed, when the current in coil *b* is two amperes. Since the number of lines of force coming from the iron bar is greater when the current in coil *b* is greater,

it proves that the amount of voltage generated is proportional to the amount of collapse.

Function of Commutator. The voltage generated in the simple alternator, cannot be used in charging batteries, whereas this is one of the things the Liberty generator must take care of. For charging batteries a direct or unidirectional current must be used. The function of the commutator is to deliver the alternating voltage, generated in the revolving coil, to the outside line as a direct voltage. It does this by reversing the connection between the ends of the revolving coil and the brushes or outside line each time the direction of the voltage in the coil reverses. This, as explained before, occurs each time the coil passes its vertical positions. A single coil generator, supplied with a commutator, is shown in Fig. 201.

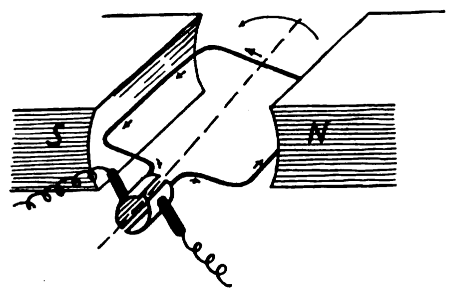

FIG. 201.—Single coil direct-current generator.

As shown in the solid line wave, Fig. 202 (*a*), the voltage delivered at the brushes of this generator is always in the same direction, but the

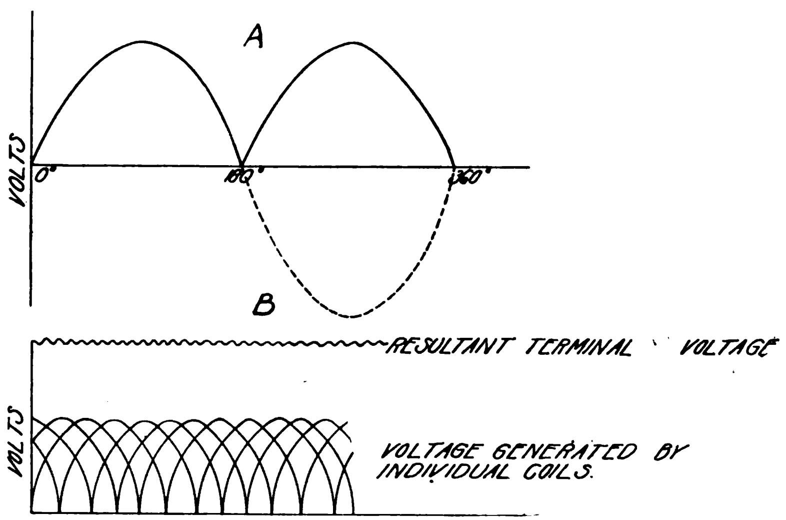

FIG. 202.—Effect of commutator; effect of using more than one coil.

changes in magnitude are still very large. In order to obtain a steadier voltage more coils are used, equally spaced around the circumference. Each coil will generate a voltage of its own and these voltages will be added together, giving a resultant which is a practically constant voltage, as shown in Fig. 202 (*b*).

Low-tension Magneto. The low-tension magneto differs from an alternating current generator insofar as its magnetic field is produced by small permanent magnets instead of electromagnets. The wave of the voltage delivered is as shown in Fig. 203.

Elements of Motor Action. Any direct-current generator can be used as a motor by simply sending current into its armature when the field coils are excited. When current flows through a coil of wire lying in a magnetic field, a force is set up, tending to turn the coil into a position at right angles to the field or in other words, the coil tends to embrace the maximum number of lines of force. In this way rotation is produced and electrical energy is converted into mechanical energy.

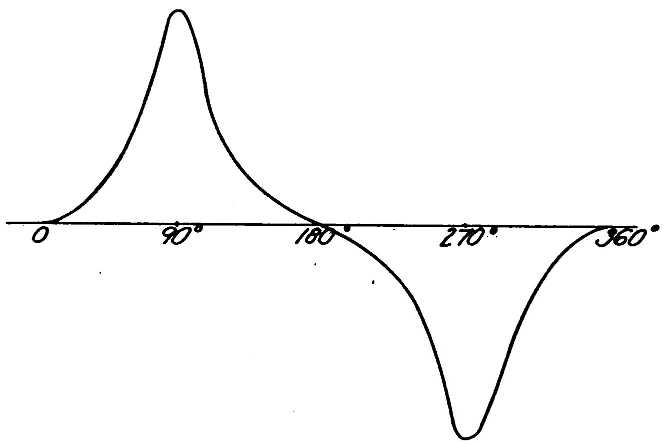

Fig. 203.—Voltage wave of low-tension magneto.

152. Elements of a Direct-current Generator. The various elements of a typical direct-current generator and their function and construction are as follows:

(*a*) *Yoke.* The functions of the yoke are twofold; to serve as the frame of the generator and to serve as a return path for the magnetic field between the poles. It is usually made of cast iron but, in the case of the Liberty generator, it is of forged steel. Fig. 204 (*a*) shows the Liberty generator yoke.

(*b*) *Pole Cores.* The function of the pole cores is to increase the strength of the magnetic field produced by the field coils. They are usually made of soft iron or forged steel. The Liberty generator is a four-pole machine, the pole pieces, Fig. 204 (*b*), being drop forgings of manganese steel. On large machines the pole cores are often laminated in order to keep down the magnetic losses due to hysteresis and eddy currents. On a machine as small as the Liberty generator it would not be economical to do this.

(*c*) *Pole Shoes.* The function of the pole shoes, Fig. 204 (*c*), is to

distribute the flux more evenly over the surface of the armature. As in the case of the pole cores, the shoes may be solid or laminated. They may also be separate or integral with the pole core. On small machines, such as the Liberty, the shoes are inte ral with the pole cores.

(*d*) *Field Winding.* The function of the field winding is to magnetize the cores when current flows in the windings. It consists of form-wound

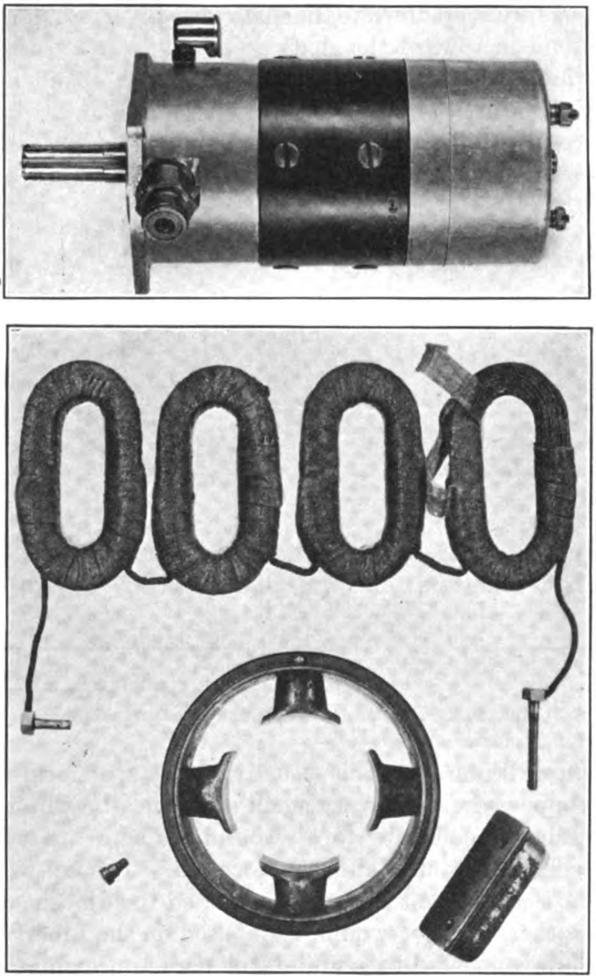

Fig. 204.—Liberty generator, yoke, poles and field coils.

coils of insulated copper wire. In the Liberty generator there are four field coils connected together in series, as shown in Fig. 204 (*d*). One terminal of the field circuit is connected to the positive armature terminal and the other is connected to the voltage regulator through which the circuit is closed to ground.

(*e*) *Armature Shaft.* This is made of steel and supports the armature core and coils. The Liberty armature shaft is shown in Fig. 206.

(*f*) *Armature Core.* This serves as a low reluctance path for the magnetic field between the pole shoes. It is usually made of soft iron or steel, laminated. The Liberty armature core, Fig. 206, is built up of sheet steel punchings in order to keep down hysteresis and eddy current losses, which would cause heating and reduce the efficiency of the machine. These punchings are solid down to the shaft whereas in most large machines they only extend in toward the shaft a short distance being assembled on a spider which is keyed to the shaft. The use of a spider reduces the weight of the armature and improves the ventilation of the machine. In any case there are slots in the circumference of the core, in which the armature coil sides are laid. The solid portions between the slots are called the teeth.

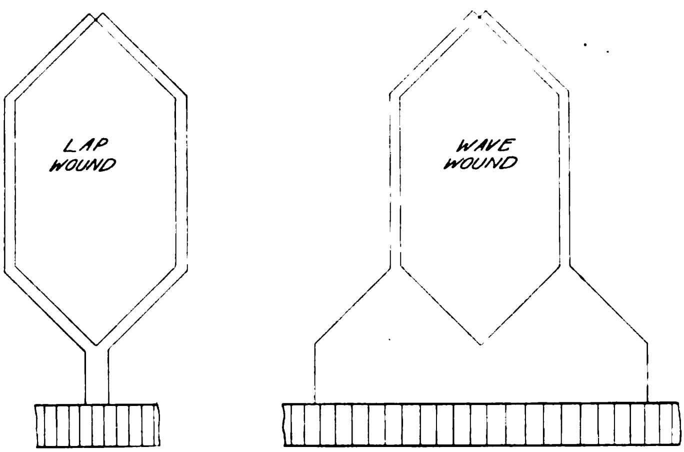

FIG. 205.—Lap- and wave-wound armature coils.

(*g*) *Armature Winding.* This usually consists of form-wound coils of insulated copper wire. On very small machines the wire is wound by hand. The Liberty coils are form wound. There are two types of form-wound coils, lap-wound and wave-wound. The lap-wound type is so constructed that the coil ends are connected to adjacent commutator bars. In the other, or wave-wound type, used on the Liberty generator, the coil ends are connected to commutator bars approximately 180 electrical degrees apart. Fig. 205 shows both a lap-wound and a wave-wound coil. The latter are sometimes called series-wound coils.

(*h*) *Binding Wires.* The function of the binding wire is to hold the coils on the armature against the action of the centrifugal force, and the mutual attraction between these coils and the field coils when both carry current. On large machines phosphor bronze is used as it is non-mag-

netic. High-grade steel wire is used on the Liberty generator. The wires are placed in slots in the circumference of the core, as shown in Fig. 206.

(*i*) *Commutator.* The functions of the commutator are to deliver the alternating current, generated in the revolving coils, to the external

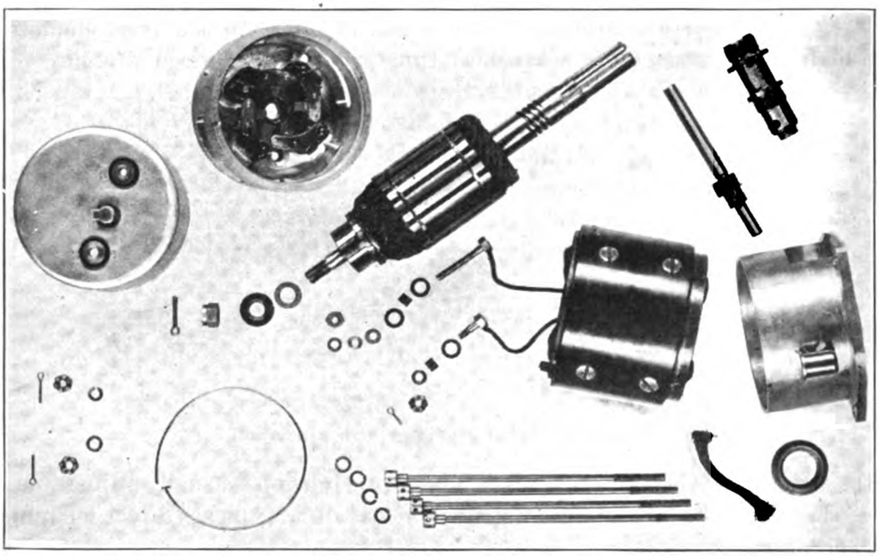

Fig. 206.—Liberty generator disassembled.

circuit as a direct current and to furnish a connection between the revolving armature-coil terminals and the stationary external circuit.

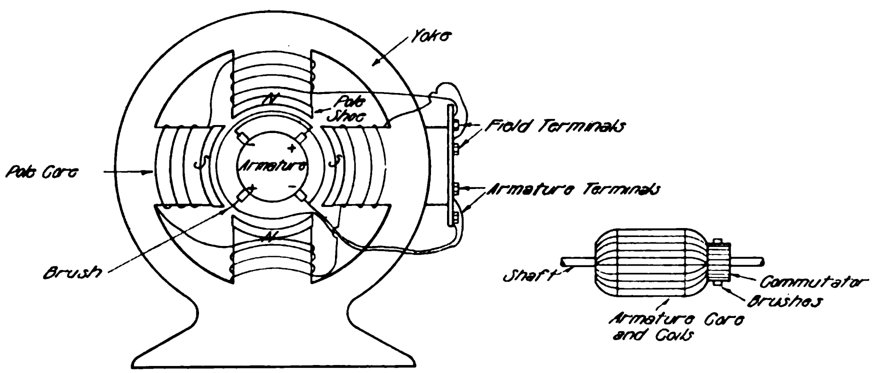

Fig. 207.—Direct-current generator.

The commutator bars are made of hard drawn copper and are insulated from each other by similarly shaped bars of mica, Fig. 206.

(*j*) *Brushes.* Brushes are used to make connection between the revolving commutator and the stationary external circuit. They consist

of carbon of graphite blocks, sometimes containing small amounts of copper to lower their resistance.

(*k*) *Brush Holders.* These are attached to a brush ring, or directly to the frame of the machine, and serve as hollow, rectangular guides for the brushes as shown in Fig. 206 (*b*).

(*l*) *Brush Holder Springs.* These are fastened to the brush holders and one end rests on the brushes, thus giving the desired pressure of

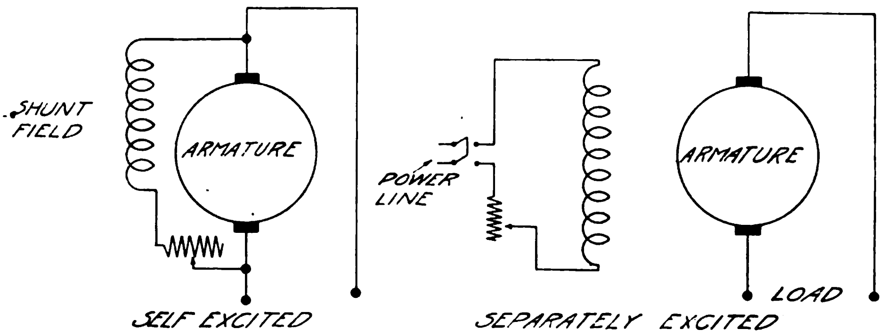

FIG. 208.—Shunt generator wiring diagram.

the brushes on the commutator. The spring tension is usually adjustable.

Fig. 207 shows the assembled elements of a typical, direct-current generator.

153. Types of Direct-current Generators. Direct-current generators are divided into three main classes, according to the manner in which the field windings are connected. Thus, we have shunt, series and compound generators.

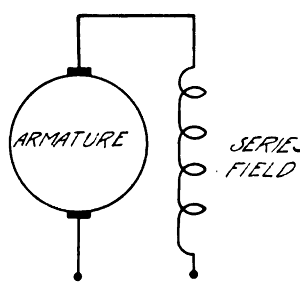

FIG. 209.—Series generator wiring diagram.

(*a*) *Shunt Generator.* The shunt generator has a field winding consisting of a relatively high number of turns of fine wire. Due to the high number of turns, only a small current is required to give the necessary magnetic field. The name, *shunt generator* is given to this type of machine due to the fact that the field terminals are usually connected across the armature terminal, that is, the field winding is shunted across the armature. The field current may be supplied by the machine itself, in which case it is called self-excited, or the current may be supplied from some entirely separate source, the machine in this case being called separately-excited. Wiring diagrams of self- and separately-excited shunt generators are shown in Fig. 208.

(*b*) *Series Generator.* The field winding in this type of generator consists of a low number of turns of heavy wire, connected in series with the generator armature. All or most of the load current passes through

this winding, thus furnishing a sufficiently strong magnetic field, due to the high current. A wiring diagram of this type of generator is shown in Fig. 209.

(*c*) *Compound Generator.* This is a combination of the shunt and series generators. It employs two separate sets of field windings, one similar to that in the shunt generator and the other a series winding, similar to that in the series generator. The series field winding may be connected in one of two ways; first, so that the magnetic field produced by it is added to the magnetic field due to the shunt field winding; secondly, so that it opposes the magnetic field due to the shunt-field winding. The former is called an accumulatively-wound and the latter a differentially-wound compound generator. Wiring diagrams of the two types of compound generators are shown in Fig. 210.

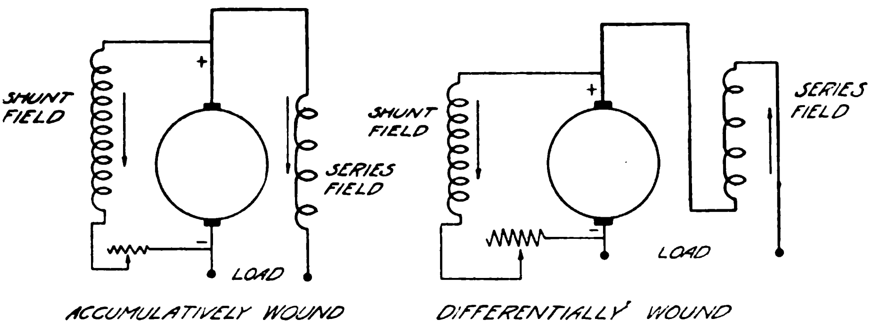

FIG. 210.—Compound generator wiring diagram.

154. Characteristics of Direct-current Generators. By the characteristics of direct-current generator are usually meant the curves showing the relation between generator-terminal voltage and load current for various values of load. As the voltage is directly proportional to the speed, these curves are taken at constant speed, thus eliminating this variable. By referring to the characteristic curves of the generators, a good idea may be gotten of the applicability of any one type to a particular class of work.

Fig. 211 shows the characteristic curves of the various types of generators. As is seen from these curves, the voltage of a shunt generator falls off rapidly with increased load. If the generator is separately excited the voltage will not fall off quite as rapidly.

In the series generator there is no field current at no load, since the field current and load current are the same. Thus, the only voltage given by this machine at no load is that, due to the residual magnetism in the field magnets which is small. As load increases the field current and the field strength also increase, resulting in an increased voltage, as shown by the curves. As the magnets approach saturation the voltage

curve begins to flatten out. Due to the fact that the voltage characteristic of both the shunt and series generators vary so widely with load, neither type is widely used in practice although the shunt generator is applicable to certain classes of work.

The characteristic curve of the accumulatively-wound compound generator can be varied within rather wide limits, depending upon the relative effect of the shunt and series fields. Due to the current in the shunt field winding alone, the voltage tends to fall as the load is increased as in the shunt generator. Due to the current in the series field winding alone, the voltage tends to rise as load is increased as in the case of the series generator. By properly proportioning the effect of the current in the shunt and series field-windings, a voltage at full load may be obtained equal to or greater than the voltage at no load. If the voltage at full load is the same as the voltage at no load, the generator is said to be flat compounded. If the full load voltage is greater than the no load voltage, the generator is said to be over compounded; and if the full

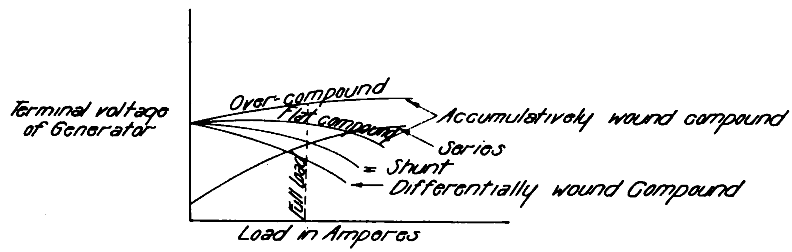

FIG. 211.—Characteristic load-voltage curves of direct-current generators at constant speed.

load voltage is less than the no load voltage, the generator is said to be undercompounded.

If the differentially-wound compound generator, since the magnetic field due to the current in the series winding tends to oppose the magnetic field due to the current in the shunt winding, the curve falls off more rapidly than in the case of the plain shunt machine. The differentially-wound compound generator finds application in ignition work, but it is not used elsewhere to any extent.

155. Methods of Voltage Control. The Liberty generator has two main functions to perform. When running double ignition it furnishes ignition current and also charges the storage battery. As before explained the generator voltage is directly proportional to its speed and this varies widely in airplane work. Below speeds of 700 r.p.m. the voltage is so low that the battery would force current back through the generator and for this reason double ignition is used only above that speed. As the speed increases the voltage and charging current tend to increase. In order to prevent abnormal charging rates at high speeds

and to maintain a uniform spark regardless of speed some method of controlling generator voltage with varying speed must be used. In ignition practice there are three principal methods of obtaining the regulation, namely, the differentially wound compound generator, the third-brush generator, and the voltage regulator.

In the differentially-wound compound generator, as before explained, the series field opposes the shunt field resulting in the voltage falling rapidly as load is increased at constant speed. On the other hand, were the speed increased, the voltage of the machine would tend to increase. By properly proportioning the weakening effect of the series field and the tendency for the voltage to rise due to increased speed, a differentially-wound compound generator may be made to deliver practically a constant voltage over a wide range of speed. The regulation of this type of machine is not sufficiently close for use on the Liberty ignition system and, in addition, were the battery suddenly disconnected at high generator speed, thus eliminating the weakening effect of the series field, an abnormally high generator voltage would result.

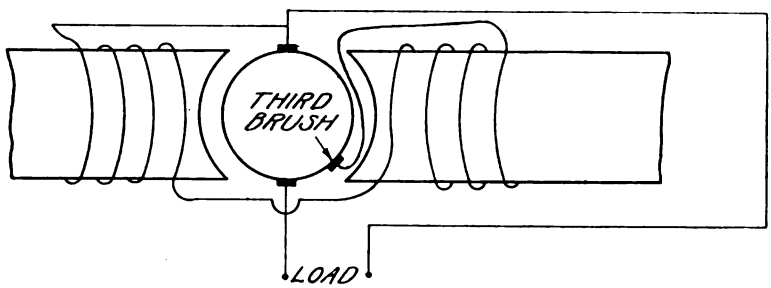

FIG. 212.—Third-brush generator.

The third-brush generator makes use of the distortion of the magnetic field with increased load. It employs one field winding, which is a shunt winding connected between one main generator brush and the adjustable third brush. Fig. 212 shows the principal elements of this type of generator.

As the load on the machine increases the field is distorted and less voltage is generated between brushes 1 and 3, thus giving less field current and a weaker magnetic field. By properly proportioning the weakening effect of the field distortion and the tendency for the voltage to rise with increased speed, a load-speed characteristic similar to that of the differentially-wound compound generator may be obtained. The adjustment is made by means of the movable third brush. As in the case of the differentially-wound compound generator, the regulation is not sufficiently close for use on the Liberty ignition system and an abnormal voltage would result were the load suddenly removed at high generator speed. An additional objection is the lack of space for the extra brush on the

Liberty generator. On a wave-wound machine only two brushes are required for collecting the current, but in the Liberty generator four brushes are used for the sake of reliability. The third-brush generator is widely used in automobile ignition work and gives very little trouble.

Voltage regulators of various types are widely used for controlling the charging rate of generators under variable speed conditions. The principle upon which they operate is that of controlling the voltage by varying the resistance of the shunt field circuit. The method in most general use, employs magnetic control in which the magnetic action of a coil, shunted across the armature terminals, controls the resistance in series with the shunt field circuit of the generator. The Liberty voltage regulator operates upon this principle.

Principles of Operation of Liberty Voltage Regulator. The circuit diagram of the Liberty voltage regulator connected to the generator is shown in Fig. 213.

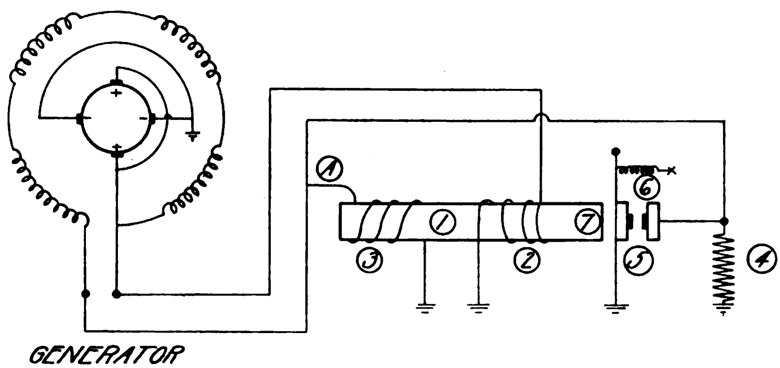

FIG. 213.—Circuit diagram of liberty voltage regulator connected to generator.

In the illustration 1 is an iron core on which are wound the three coils 2, 3 and 4, in the same direction. The reverse coil, 3, is so connected that it tends to magnetize the core in a direction opposite to that of the voltage coil 2. The reverse coil, contact points 5, and the non-inductive resistance 4, are all connected in parallel at *a*. The armature 7, is attracted by the magnetism in the core and thus opens the contact points 5, against the tension of the spring 6.

As shown in the diagram, one end of the voltage coil is connected to the positive terminal of the armature and the other end is grounded. Since the negative generator-armature terminal is also grounded the full generator terminal voltage is impressed across this voltage coil. As in the case of the voltage coil, the circuit through the reverse coil, non-inductive resistance and contact points is completed through ground, as shown in the illustration. The generator field current goes from the positive generator armature terminal through the four field coils to *a*,

where it has three parallel paths to ground; first, through the reverse coil, secondly, through the non-inductive resistance and thirdly, through the contact points, if they are closed.

Assume that the regulator is set for 10.0 volts. As the generator speed and voltage increase, the latter will reach 10.0 volts. Under this condition the pull of the core on the movable armature is strong enough to overcome the opposing spring tension, and the contact points open. While the contact points are closed there is practically no resistance in series with the shunt field circuit of the generator and we have maximum field current through the contact points to ground. As soon as the contact points are opened, the shunt field current must flow through the non-inductive resistance and the reverse coil. Since each of these paths has a relatively high resistance the shunt field current is reduced and the generator terminal voltage falls. When the voltage has fallen a certain amount, the magnetism in the core is no longer sufficient to hold the armature against the pull of the spring, the contact points close and the field current and generator voltage again rise. This cycle of operations takes place continuously; the higher the generator speed the more rapidly the regulator armature vibrates.

The reverse coil improves the regulation and at the same time speeds up the action of the regulator. After the movable armature has been drawn in toward the core, it requires much less voltage to hold it there than was required to draw it over, against the action of the spring. Therefore, the voltage of the generator would have to fall considerably, before the armature would be drawn away by the tension of the spring. As soon as the contact points open current flows through the reverse coil and wipes out some of the magnetism produced by the voltage coil. Thus the pull of the core is considerably decreased and the generator voltage has to fall only slightly before the points again close.

The non-inductive resistance, in addition to lowering the field current when the contact points open, absorbs the energy change in the field circuit due to the sudden drop in current, and thus prevents arcing across the contact points. A condenser was at first used across the points but this caused the contact points to weld together.

156. Generator Operating Troubles. Generator operating troubles may be divided into three general classes, namely, low generated voltage, sparking and overheating. These may be further subdivided as follows:

(*A*) Low generated voltage may be due to:

1. Armature trouble such as,
   (*a*) Low speed. Generated voltage is directly proportional to the speed which is controlled by the engine.
   (*b*) Open-armature coil. Normal voltage is generated in the open coil but is not delivered to the commutator.

(c) Short-circuited coil. Normal voltage is generated in the coil but is partially or entirely used up in forcing current around the short-circuit path. The short-circuit may be caused by two grounds in the armature. Only one is necessary in the Liberty generator since the negative armature terminal is intentionally grounded.

2. Field trouble such as,
   (a) Field-circuit open causing zero field current and no magnetic field.
   (b) Regulator trouble. Any fault causing the resistance in the field circuit to be too great.
   (c) Field coil short-circuited. Reduces the number of effective ampere turns in the field.
3. Brush trouble such as,
   (a) Brushes off neutral. Shifted past the neutral point in the direction of rotation.
   (b) Brushes off commutator or tension too low. The latter causes an abnormal voltage drop at the brush contacts, thus resulting in low voltage at armature terminals.

(B) Generator sparking may be due to:
1. Brushes off neutral in either direction.
2. Brush-spring tension too low. Results in a gap across which the voltage causes an arc to be drawn.
3. Brushes sticking in holder. Same effect as 2.
4. Brushes not trimmed. Same effect as 2.
5. High mica. Copper wears away more rapidly than the mica, allowing the latter to protrude. Same effect as 2.
6. Low mica. This is desirable in many cases, but it may cause a partial short-circuit between the bars if any conducting particles are allowed to collect and settle between the copper bars, where the mica has been cut out.
7. Soft brushes cause a dirty commutator with resulting partial short-circuit between the copper bars.
8. Hard brushes cause an uneven wavy commutator surface. Ridges are worn in the surface and the brushes do not seat properly giving the effect of improperly trimmed brushes.
9. Open-armature coil. When this passes under a brush it causes the current in that part of the armature between this brush and the following one to fall to zero. This sudden change in current causes an arc at the brush.

(C) Generator overheats.
1. Commutator overheats due to:
   (a) Any fault causing sparking causes the commutator to over-

heat, since the spark transforms electrical energy into heat energy.

(b) Brush pressure when too great, causes abnormal friction between brushes and commutator.

2. Armature overheats due to:
   (a) Overload beyond capacity. This may be caused by a short-circuit or ground in the external line. The heat produced by an electric current passing through a resistance is proportional to the square of the current.
   (b) Short-circuited armature coil. The current in this short-circuited coil may reach many times the normal value, causing excessive heating.
3. Fields coils overheat due to:
   (a) A short-circuit in the winding. This lowers the total resistance of the field circuit and allows an abnormal amount of current to flow in that portion of the winding not included in the short-circuit.

Storage Batteries

157. Liberty Storage Battery. The Liberty storage battery must supply ignition current when running single ignition. If something should happen to the generator it would have to supply current for double ignition. The government specifications require that the battery supply 3 amperes for 3 hours or have a capacity of 9 amp-hr. at this rate, without the voltage falling below 1.77 volts per cell. It must also be able to operate in an inverted position. This capacity is sufficient to supply single ignition for about 8 hours, double ignition for about 3 hours, and it will operate in an inverted position on single ignition for about 2 hours.

The battery is made in two types: The Willard SY-13, made by the Willard Storage Battery Co., and the Exide 4-AC-7, made by the Electric Storage Battery Co. They are practically identical except for a few minor details. The Liberty battery is a four-cell, lead plate battery giving about 8 volts. The capacity of the battery is as follows:

3 amperes for 3 hours.

1.4 amperes for 8 hours.

1.4 amperes for 2 hours with the battery inverted.

158. Types of Cells. Cells may be classified into:

1. Primary cells.
2. Storage or secondary cells.

Some examples of primary cells are:

1. Gravity cell.
2. Bichromate cell.

3. Leclanche or salamoniac wet cell.
4. Dry cell or salamoniac dry cell.
5. Edison primary cell.

The secondary or storage cells are of two different types:

1. Lead or acid type.
2. Edison or alkaline type.

When a primary cell is discharged, some of the elements are destroyed and must be replaced before the cell can be brought back to its original

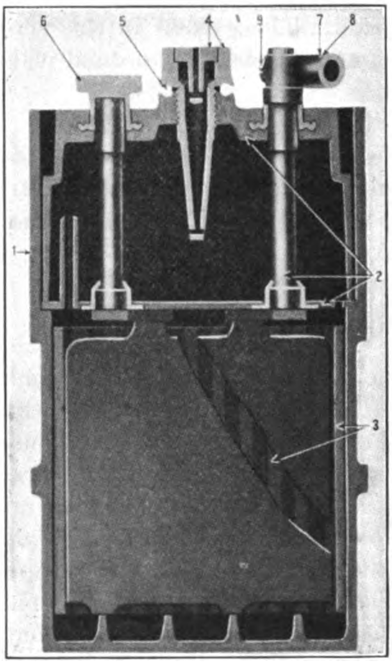

Fig. 214.—Section of Willard battery, type SY-13.

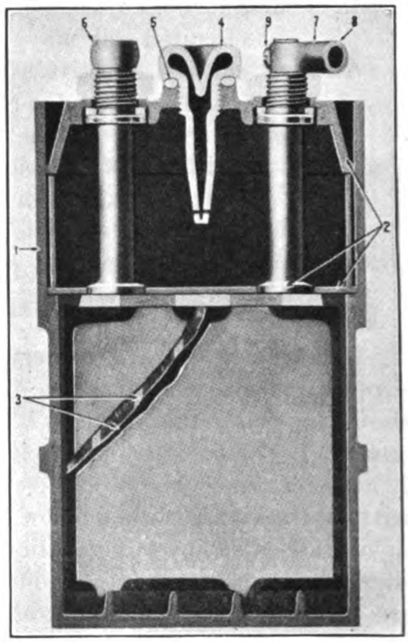

Fig. 215.—Section of Exide battery, type 4-AC-7.

charged condition. In a secondary cell upon discharge a chemical action takes place which can be reversed and the original charged condition obtained again by running the current through in the opposite direction.

The only primary cell used in ignition work is the dry cell. The elements of this cell are: the negative electrode, a zinc cylinder which also serves as a container. The positive electrode, a carbon rod placed in the center of the zinc cup. Next to the zinc cup is a soft paper or pulp board, saturated with salamoniac and zinc chloride. The salamoniac is the electrolyte, while the zinc chloride is added to reduce the rapid deterioration which would take place on open circuit. The space between this layer and the positive pole is filled with crushed carbon, and manganese dioxide. The top is usually sealed with a pitch compound.

The voltage of this cell is about 1.53 volts and should give 30 amp. on a short circuit test. The dry cell can be used to supply current for ignition, for a short time only and is not a reliable means for supplying that current for any definite time, so it is not used for airplane ignition work.

The two types of storage cells named differ in construction as well as characteristics. The Edison cell when charged consists of positive plates of nickel oxide and negative plates of iron immersed in potassium hydrox-

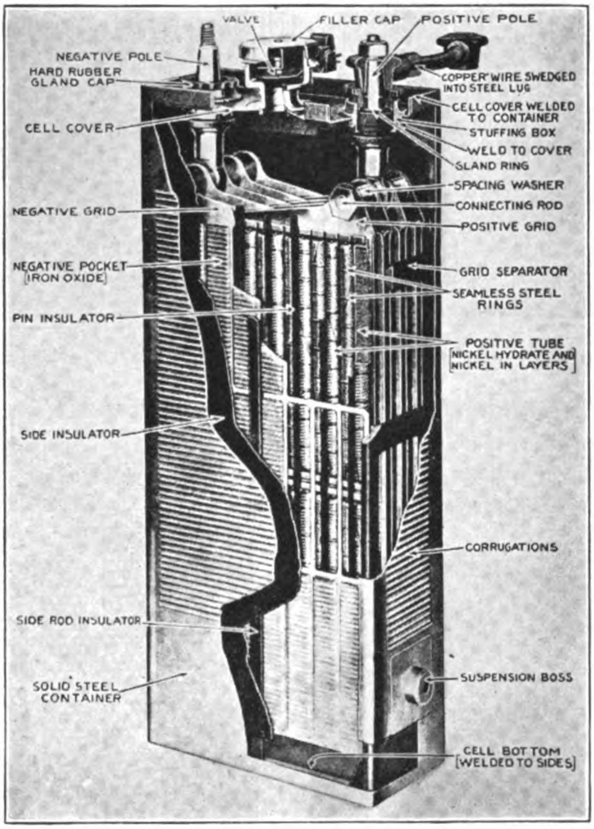

Fig. 216.—Edison storage cell.

ide. When discharged the plates become oxidized and can be left in this state without materially harming the cell. An Edison cell can also be discharged to the limit of its capacity, that is, to zero volts without injury. It, however, gases all the time it is on charge. The gas evolved is composed of oxygen and hydrogen which is an explosive mixture.

The voltage of this cell is only 1.2 to 1.4 volts. Therefore more Edison cells would be needed to give the necessary ignition voltage. No Edison cells have been used in airplane ignition work up to this time.

The lead cell when charged consists of positive plates of lead peroxide and negative plates of spongy lead immersed in a solution of dilute sulphuric acid. The lead cell can not be discharged below a certain voltage or left in a discharged condition without injury. It gases only when nearly charged.

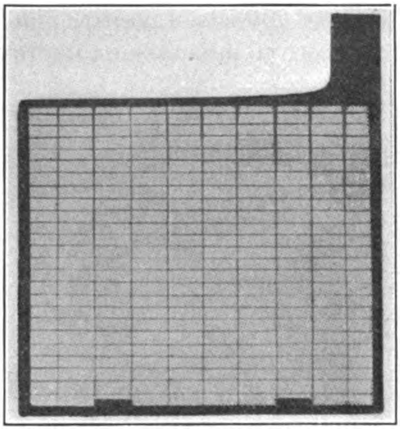

Fig. 217.—Positive plate.

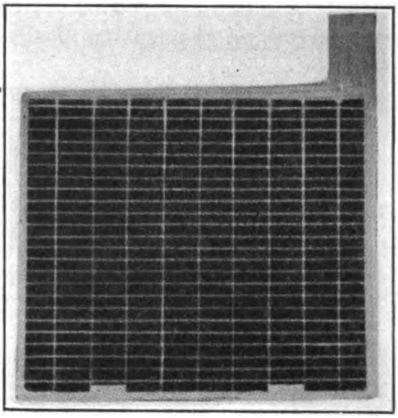

Fig. 218.—Negative plate

This cell gives an average of 2.0 volts between terminals. With the 8-volt system used on the Liberty only four lead cells are required, where if Edison cells were used seven would be necessary.

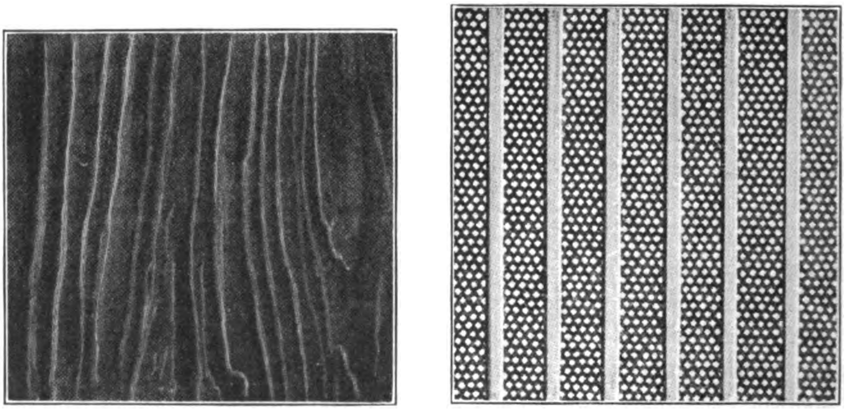

Fig. 219.—Rubber and smooth wood separator.

159. Elements of a Lead Cell. The necessary elements of a lead storage cell are:

1. Positive plates. Lead peroxide. Chocolate brown in color.
2. Negative plates. Spongy lead. Grey in color.

There is always one more negative plate than positive plates.

3. Separators. Non-conducting material that will permit of the circulation of the electrolyte. Some types of separators are:

a. Rubber and smooth wood; used in Exide Liberty.

b. Grooved wood; used in Exide Liberty.

c. Cotton and rubber; used in Willard Liberty.

4. Electrolyte—Dilute sulphuric acid. It may be from 1.200 to 1.320 specific gravity when charged, depending upon the type of battery. It is made from concentrated sulphuric acid with a density of 1.835 at 70° F. diluted with water to the desired density. In battery practice it is customary to omit the decimal point in referring to the density of the electrolyte. For example, a density reading will be given as 1,200 in-

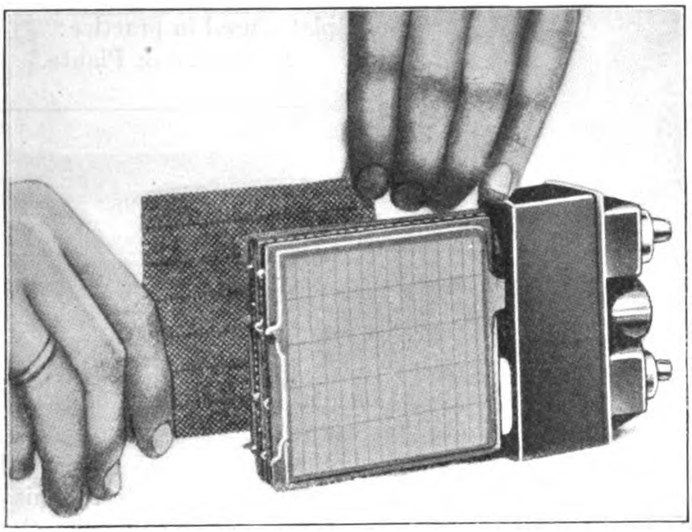

Fig. 220.—Grooved wood separator.

stead of 1.200. The reason for this is that a person not thoroughly familiar with the matter might think that a figure in the second or third decimal place was not important and might disregard it. For example, if the reading was given as 1.275, he might quote it as 1.2, whereas the difference between 1.275 and 1.2 would represent the difference between a fully charged battery and an almost totally discharged battery. If the reading was given as 1,275 he would be more apt to be impressed with the importance of the last two figures.

5. Straps—All positive plates in one cell are connected together by a lead strap, and the assembly is called the positive group. Similarly, all the negative plates are connected together by a strap and are called the negative group.

6. Container—Hard rubber or glass jar. When the container is a

hard rubber jar it has a hard rubber cover which is sealed with a pitch compound called battery sealing compound to keep out the dirt.

7. Vent Plug—The purpose of the vent plug is to allow for filling, and to take gravity readings. It is provided with a small hole to permit the escape of the gas formed in charging.

8. Connecting Links—If a number of cells are used in a battery, as in the Liberty, the cells are connected together by connecting links which are made of pure lead, or copper or brass covered with lead.

There are three types of lead plates used in practice:

1. Formed or Plante.
2. Pasted or Fauro.
3. Ironclad.

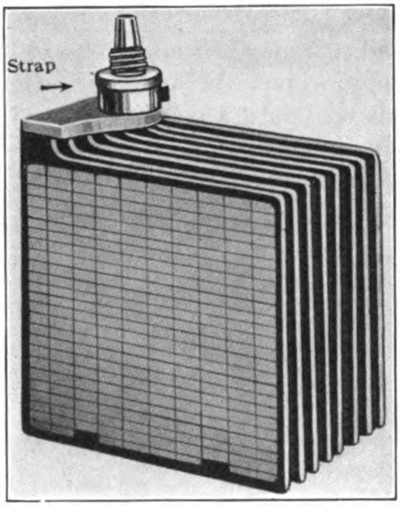

FIG. 221.—Strap and group.

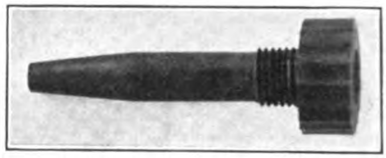

FIG. 222.—Vent plug.

The formed plate is a heavy thick plate formed electrolytically. Both the positive and negative plates are first formed by taking solid lead plates and charging them as positives in a tank of sulphuric acid, using dummy negative plates. This produces a coating on the plates of lead peroxide, a chocolate brown substance. Negative plates are obtained by again charging some of these formed plates in another tank of sulphuric acid using dummy positive plates. On this charge the current flows through the plate in a reverse direction to that of the forming charge, changing the lead peroxide to spongy lead. The spongy lead of the negative plate, and the lead peroxide of the positive plate are called the active material. It is the amount of this active material which determines the capacity of a battery. In order to provide the maximum surface and hence the maximum amount of active material, the surface of the original lead plate is grooved. Only about 25 per cent. of a formed plate is active material. Therefore this type has a relatively small capacity for its weight, but its construction is rugged and its life long. It is used in station work where weight is of little concern, and in train lighting where the service is severe.

FIG. 223.—Connecting link.

The pasted plate is made by taking a grid composed of lead with 5 per cent. antimony and pressing into it the active material in the form of a paste, after which it is baked. The active material of the positive plate is, to start with, red lead, and that of the negative plate is litharge, both of which are oxides of lead. Upon charging, the red lead becomes lead peroxide, and the litharge becomes spongy lead. About 50 or 60 per cent. of these plates become active material so this type has a large capacity for its weight; but it has a shorter life due to a tendency of the active material to drop out of the grid. This type is used in automobiles when it is desirable to save weight and get high capacity. The plates shown in Fig. 217 and 218 are the pasted type.

In the Ironclad plate, which is made into positive plates only, the antimony lead grid consists of thin vertical rods, each of which is sur-

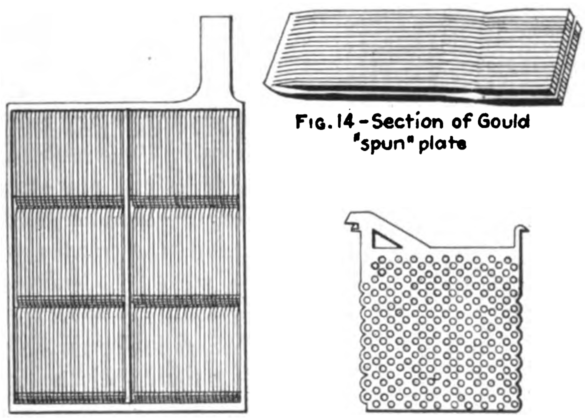

Fig. 14 - Section of Gould "spun" plate

Fig. 13.- Gould "spun" plate Fig. 15 - Manchester positive

Fig. 224.—Formed plates.

rounded by a slotted hard rubber tube. The active material is placed between the vertical grid rod and the tube. The plate is then dried and given its forming charge before being fastened to the positive straps. Due to the slotting of the rubber tube, the plate has a large surface and permits free circulation of acid and minimizes the loss of active material. In the Ironclad type the negative plate is of the same construction as in the pasted type.

Electrochemical action in a cell: When a cell is fully charged the positive plate becomes lead peroxide and the negative plate spongy lead and the specific gravity of the electrolyte is a maximum. Chemical energy is stored in a cell in this condition.

If the cell is put on discharge the sulphate ions of the acid combine with the lead peroxide forming lead sulphate and with the spongy lead forming lead sulphate. This lead sulphate is deposited on the surface of

the positive and negative plates. The acid of the electrolyte thus being robbed of its sulphate ions becomes weaker and the specific gravity of the electrolyte becomes less. The voltage of the cell also falls. As the discharge continues this effect becomes more pronounced and the closed circuit voltage drops very fast due to the increased internal resistance. Discharge should be stopped when the gravity and voltage have fallen to the low limit for that particular battery. The low limit of the electrolyte density of the Liberty is 1,190 and the low voltage limit is 1.75 volts, when discharging at normal rate or 3 amp. If discharge is continued the plates become excessively sulphated and the battery is ruined. If the battery is left standing in a normal discharged condition the sulphate will harden on the plates which would also have a ruinous effect.

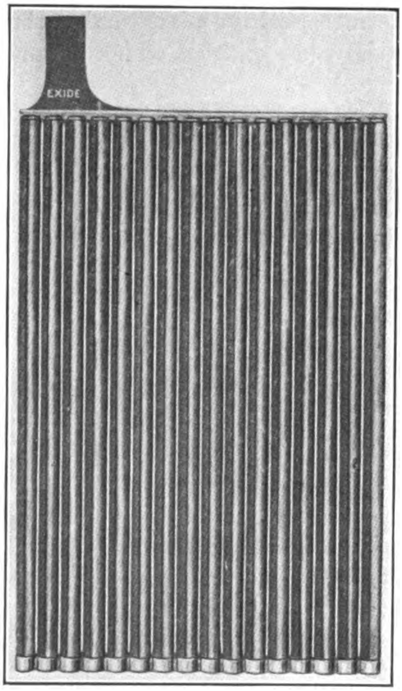

FIG. 225.—Ironclad positive plate.

On charging, direct current is passed through the cells in the opposite direction to that of discharge and the action inside the cell is therefore reversed. The sulphate ions are driven from the plates into the electrolytes, the specific gravity of which rises, and the plates assume their former state of lead peroxide and spongy lead. When the battery is fully charged the gravity of the electrolyte should be the same as before discharge. When the battery has been discharged beyond its limit and allowed to stand, some of the sulphate becomes of a permanent character, and upon being charged can not be changed back into active material. This results in low voltage and low capacity.

160. Construction of Liberty Battery. The Liberty battery has two compartments which are separated by a rubber baffle plate provided with drain holes. The lower compartment contains the plates and the electrolyte, while the upper compartment is empty when the battery is in an upright position. When the battery is inverted the electrolyte drains into the upper compartment. Enough electrolyte remains in the plates and separators to enable the battery to supply current for single ignition for about two hours. The vent plugs are of sufficient length so that when the battery is inverted the opening or vent extends above the

level of the electrolyte and none will be spilled. Seven pasted type plates are used, four negative and three positive, both being $\frac{3}{32}$ in. thick.

The difference in the Exide and Willard Liberty batteries will be found in:

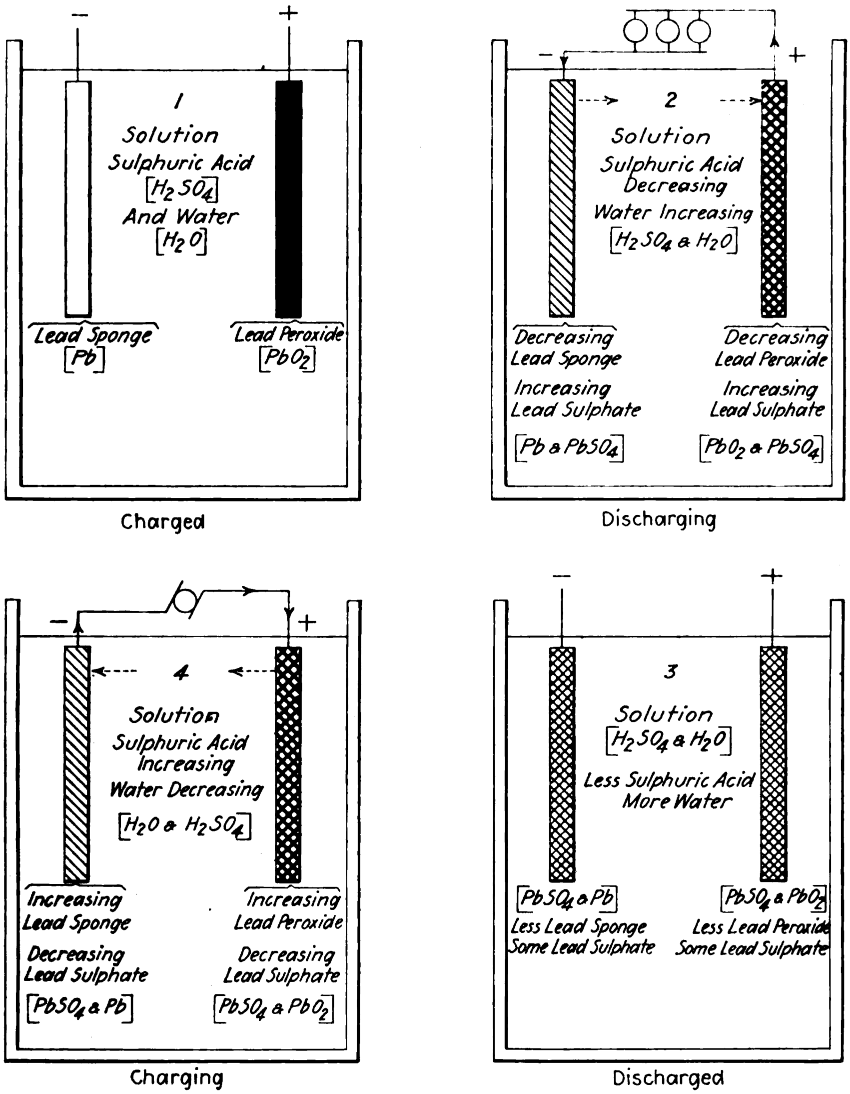

FIG. 226.—Diagram showing essential actions in storage battery.

1. Separators. The Exide uses grooved wood or rubber and smooth wood. The Liberty uses a cotton and rubber separator.

2. Baffle plate. The Exide uses no washer between the post and plate while the Willard does. There is also a difference in the location of the breather pipe and drain holes.

3. Top cover. The Exide uses a spacer with the top cover, whereas in the Willard the spacer and top cover are combined in one piece.

4. Post and cover connection. In the Exide the cover fits down onto a shoulder on the post, a rubber washer being used to make a tight connection, and held in place with a lock nut. In the Willard the post fits up into a lead sleeve which is vulcanized into the cover, and a tight connection is made by burning the two together.

5. Connecting link. The Exide link is about ¼ in. thick and quite narrow. That on the Willard is about half as thick and much wider.

161. Capacity, Hydrometer Readings. The capacity of a battery is measured in ampere hours, which is the product of the number of amperes it will deliver, multiplied by the time in hours during which it will deliver it. The rated capacity of a battery is usually based on an eight-hour discharge at a certain normal rate in amperes. For example, a battery which is rated at 80 amp.-hr. on an eight hour basis, will deliver 10 amp. for eight hours. A battery will give its rated capacity only when discharged at its normal rate. If discharged at a higher ampere rate than normal it will give less than rated capacity, and conversely if discharged at a lower ampere rate than normal it will give more than rated capacity: The capacity of the Liberty battery at several different rates is as follows.

1 amp. for 11.5 hours = 11.5 amp.-hr.
1.4 amp. for 8 hours = 11.2 amp.-hr.
3 amp. for 3 hours = 9 amp.-hr.

The capacity of a battery also depends upon the temperature of the electrolyte. The higher the temperature the greater the capacity. A battery cannot, however, be heated above 110° F. without injury to it.

The hydrometer is used to obtain a reading of the density or specific gravity of the electrolyte. The tube of the syringe is inserted into the vent of a cell and the electrolyte is drawn up into the glass barrel by means of a rubber bulb. In order to obtain the correct reading the hydrometer should float free in the barrel from ½ to ¾ in. from the base. Care should be taken to see that the hydrometer does not stick to the bottom or sides.

A hydrometer reading will give an indication of the condition of a battery, but first it is necessary to know the battery, its specific gravity, and its range. To specify a reading of any battery means nothing unless the facts above are known. For example, a reading of 1200 would represent a fully charged station battery, while the same reading on a Liberty battery would mean that it was practically discharged.

All hydrometer readings before being reported or recorded in any way should first be corrected to the equivalent density at 80° F. Electrolyte, like other substance, will expand with heat and contract with cold. Therefore the specific gravity will vary inversely with the tem-

perature. This change amounts to 1 point, the difference between 1200 and 1201 being one point, for every 3° F. change in temperature. For example, it will be assumed that a battery reads 1200 at 50° F. The difference between 50° and 80° is 30°. Therefore the gravity must be corrected for 30°. If 3° is equivalent to 1 point in the gravity, 30° is equivalent to 10 points. The gravity will be less at 80° than at 50°. Therefore the equivalent gravity at 80° F. will be 1190.

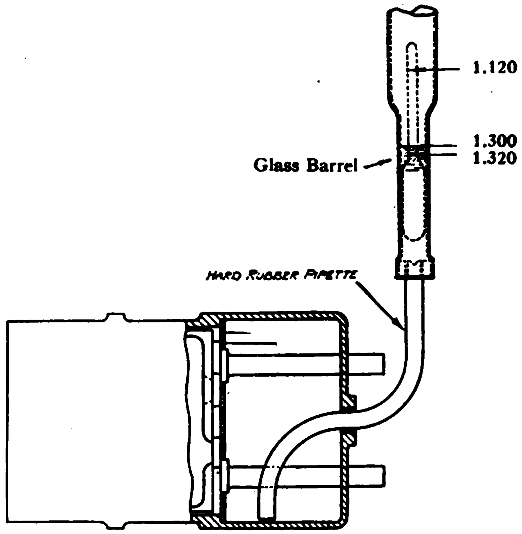

FIG. 227.—Taking hydrometer reading.

162. Electrolyte. The specific gravity of electrolyte varies in different types of batteries according to the service for which they are to be used. The higher the gravity of the electrolyte the higher will be the voltage and capacity of the battery. High gravity electrolyte, however, tends to shorten the life of the battery and to increase the danger from contamination. By the latter is meant that if impurities, such as iron or copper, get into a battery, they will injure it and the extent of the injury will be greater, the higher the gravity of the electrolyte.

A station type battery when fully charged has a specific gravity of about 1200, and when discharged about 1100. An automobile battery has a gravity of about 1270 when charged and about 1140 when discharged. A Liberty has about 1300 to 1310 when charged and 1190 discharged.

To prepare electrolyte of 1300 specific gravity at 70° F. from sulphuric acid of 1835 specific gravity, mix by volume, 1 part of acid with 2½ parts of water. For 1260 electrolyte, mix by volume, 1 part of acid to 3 parts of water.

In mixing the electrolyte, the following precautions should be ob-

served: A glazed stone or glass vessel, or a lead lined tank should be used. Pour the water in first and then add the acid slowly stirring the solution with a glass rod or a clean piece of wood. *Never pour the water into the acid.* Allow the solution to cool before pouring it into the battery.

163. Charging. There are three conditions under which the Liberty battery may be charged:

1. The battery charged on the plane by the Liberty generator. In this case the charging rate depends upon the condition of the battery. If the battery is in a discharged state the voltage will be low, about 7 volts. When running above idling speed the voltage of the generator is 10 volts. Therefore the charging rate will be high, probably about 15 amperes. As the battery becomes charged its voltage rises and the charging rate decreases. For example, when the battery voltage is 9 volts, the charging will be reduced to probably 4 or 5 amperes. When the battery is fully charged its voltage is 10 volts which is the same as the generator voltage. It will then be floating on the line, that is, neither charging nor discharging.

2. The battery charged from an outside source. Charge should be started at 1.9 amperes and this rate continued until the battery gases, or the temperature rises to 110° F. Then the rate should be cut down to 0.6 amperes and the charge continued at this rate until the battery again gases or reaches a temperature of 110° F. The battery is then fully charged.

3. Charging a new battery: When a Liberty battery is shipped dry, the plates are not fully formed and need a special initial charge. The battery should first be filled with electrolyte, the specific gravity of which is 1260. The battery should then be put on charge at 0.7 amperes and this rate continued for 70 hours. During this time the gravity will rise 40 or 50 points due to the fact that when the plates are made some sulphate remains in them, and on the initial charge this sulphate is driven back into the electrolyte.

To test the battery it should be discharged at 20 amperes. If at the end of 15 seconds the voltage has not fallen below 1.55 volts per cell the battery is in good condition.

In all cases the battery must be charged with a direct current. If a direct current line is available, a suitable rheostat is all that is necessary. If only alternating current is available, it must be rectified or changed into direct current before being used for charging. There are several methods employed for accomplishing this. One method is to use a motor generator set, which consists of an alternating current motor driving a direct current generator. Other devices are, the mercury arc rectifier and the Tungar rectifier.

Demonstrations during Study Period.

1. Determination of the polarity of a direct current line. Before

connecting a battery to a line for charging it is necessary to determine the polarity of the line. This may be determined by either of the following two methods:

a. Salt solution: Place the two ends of the leads from the line in salt water. Bubbles of hydrogen will rise from the negative lead.

b. Direct-current voltmeter. The voltmeter has a terminal marked + (positive). Connect one terminal of the voltmeter to one terminal of the line, and tap the other terminal of the line lightly with the voltmeter terminal. If the deflection of the voltmeter needle is in the right direction, then the positive terminal of the voltmeter is connected to the positive terminal of the line.

2. Connections for charging batteries. The positive of the line should be connected to the positive of the battery with a rheostat in series. A voltmeter should be placed across the battery. The charging switch should then be closed and if the reading on the voltmeter goes higher the connection is correct.

3. Study blueprint of Liberty battery section.

Diseases of Storage Batteries

164. Freezing of Batteries, Grounds, Bad Connections. If the electrolyte in a battery freezes, it will expand, causing the plates to buckle and break the separators. The breaking of the separators will short circuit the cell and put it out of commission. If the freezing is extreme it may crack the jar, or in the case of a Liberty battery crack the baffle plate. When the battery is thawed out, it will leak and the electrolyte will eventually all be lost. In short, freezing of a battery will seriously damage if not completely ruin it.

The temperature at which a battery will freeze depends upon the density of the electrolyte, that is, the lower the density, the higher is the temperature at which it will freeze.

The temperatures at which a battery will freeze for various densities of electrolyte is given in the following table.

TABLE XVIII.—FREEZING TEMPERATURE OF BATTERIES

Battery will freeze at	If specific gravity is below	
	Referred to 80° F.	Referred to temp. at which read
25° F. above zero	1029	1047
20° F. above zero	1067	1087
15° F. above zero	1090	1112
10° F. above zero	1114	1137
0° F.	1135	1162
10° F. below zero	1157	1187
20° F. below zero	1169	1202
30° F. below zero	1180	1217

The temperature referred to is the temperature of the electrolyte. It should be borne in mind that the electrolyte of a battery is heated during charge or discharge so that when a battery is in operation, its temperature may be considerably higher than the temperature of the outside air.

Grounds are a great source of trouble and, in most cases, are the result of carelessness. Two kinds of grounds are found in general practice, and are known as acid grounds and metallic grounds.

If acid is spilled over the top of a battery and left there it will form a conducting path between the terminals of the battery, and cause the battery to discharge. This acid also tends to collect dust, forming a paste on the outside of the battery which will be a source of constant leakage. If acid is allowed to run down the sides of the battery it will attack the wooden base or charging bench. This acid-soaked wood forms a conducting path which is likely to discharge a cell left standing on it for any length of time. The best preventive for acid grounds is to be careful in handling electrolyte and not to spill it around the battery. Where it is accidentally spilled it should be wiped up with a cloth moistened with ammonia. Soda is sometimes used for the same purpose, but is open to the objection that it usually contains iron which may get into the battery and injure it. A wooden battery box, base or charging bench should be painted with asphaltum paint to resist the action of any acid spilled on it. This paint should be renewed as the most important precaution in avoiding trouble from leakage.

A metallic ground is usually due to a loose connection which comes in contact with the ground. It may also be due to poor insulation on a battery lead. Any ground on the position side of a grounded system will act as a short circuit and discharge the battery. A slight ground is not always readily detected and may require going over all the connections thoroughly. Connections should be examined frequently to see that they are tight and that the insulation is in good condition. Tools must not be left loose in a position where they can fall on the battery and cause a ground or a short circuit.

Bad connections may be caused by, (*a*) loose connections; (*b*) acid which has been spilled on the top of the battery, attacking the copper lead and producing copper sulphate which has a high resistance and (*c*) poorly burned-in connector; that is, a connecting link not properly fused to the post, so that it does not make a good electrical connection.

The result of a poor connection is to introduce a high resistance into the battery circuit and thus cause a voltage drop across the poor connection. In an ignition system, this would give a low voltage across the coil, and result in a weaker spark and possible misfiring of the engine.

A poor connection will also require a higher voltage to charge the

battery. On the Liberty system where the generator supplies a constant voltage, the charging rate would be lower than normal.

All contacts should be thoroughly cleaned before making connections and if there is any chance of acid having come in contact with them it should be neutralized with ammonia. The connectors and terminals of a battery should be protected from corrosion by a coating of vaseline. A poor connection can usually be detected by the fact that it is hot.

165. Sulphation. During a normal discharge of a battery lead sulphate is formed on the positive and negative plates. If the discharge is not carried beyond the safe limit (1.75 volts per cell and a density of 1180 in the Liberty battery), upon recharging, this sulphate will be changed back into acid and active material. If the discharge is carried beyond the low limit of voltage and electrolyte density or if the battery is allowed to stand in a discharged condition, a certain amount of the sulphate becomes of a permanent character and cannot be removed by charging. Lead sulphate is practically a non-conductor of electricity and that portion of the plate which is sulphated becomes permanently inactive. Hence that much of the capacity of the battery is lost. The internal resistance of the battery is also increased.

Lead sulphate occupies a larger volume than the active material from which it is formed, which results in expansion of the plates. Some of the injurious effects of sulphation are: (*a*) high internal resistance; (*b*) high voltage required to charge; (*c*) low voltage on discharge; (*d*) low capacity; (*e*) swollen or buckled plates; (*f*) broken separators; (*g*) cracked containers; (*h*) short circuited plates.

Sulphation is the worst of the diseases occurring in batteries. It has been properly called the "White Plague" of batteries. If a battery has been badly sulphated, nothing can be done to repair the damage and it is necessary to replace the plates, or in some cases the whole battery. If a battery is only slightly sulphated, it may be possible to remove the sulphation by a long charge at a low rate. In any case, however, even though it may be possible to again get the battery into working condition, a certain amount of permanent injury has been done to it. The importance of giving batteries the necessary care to avoid sulphation cannot be too strongly emphasized.

166. Impurities, Shedding. The most common impurities found in storage batteries are sea water, copper, iron and impurities due to plate manufacture such as nitrates and arsenic. Sea water may enter a battery from spray. It will not produce any injurious effect on the battery, but is objectionable because it causes a poisonous gas, chlorine, to be given off on charge and discharge. The sea water can all be eventually worked out of a battery by repeatedly charging and discharging it.

The most probable source of contamination from iron is water. Only

distilled water, or water that has been given a chemical analysis and found to be satisfactory should be used in a battery.

Copper may get into a battery due to acid creeping onto the copper connections and forming copper sulphate, particles of which fall into the battery when the vent caps are off.

Both iron and copper produce a parasitic action in the battery, that is, they form little local cells within the main cell and cause an internal discharge. The result is low voltage, low capacity and short life.

If the presence of the impurity is discovered promptly after its introduction into the cell, the remedy is to dump out the electrolyte and replace it. Otherwise, if the impurities get into the plates, it is usually necessary to renew the plates.

Shedding. By the term shedding is meant the loss of the active material of the plates. It is confined almost entirely to the positive plates. The usual causes of shedding are overcharging, or freezing. When a battery is overcharged it gases, and the churning action produced by the gassing tends to knock the active material off the positive plates. In addition, gas blisters form on the surface of the plates and when these break some of the active material drops to the bottom of the cell. If a battery is repeatedly overcharged, the sediment formed in the bottom of the cell will eventually fill up the mud cellar and will short-circuit the plates.

167. Hardening of Negatives, Fracture and Buckling of Plates, Low Electrolyte Level. Hardening of the negative plates is caused by exposure to air. This will result if the level of the electrolyte is allowed to fall below the top of the plates. It can also occur when a battery is disassembled. When the negative plates are removed from a battery and exposed to the air they will have a tendency to heat up and hardening will result. To avoid this they should be sprinkled with water every few minutes to keep them cool. A negative plate which has become hardened will no longer perform its function.

Fracture and buckling of plates may be caused by the following:

(*a*) *Sulphation.* The conditions producing sulphation have been previously explained.

(*b*) *Overcharging.* In charging a battery the temperature should not be allowed to rise above 110° F. If the temperature rises above this value it will tend to buckle the plates and perhaps fracture them if carried far enough.

(*c*) *Discharging at too High a Rate.* This will also cause overheating with the results explained in the previous paragraph.

Low electrolyte level is the result of carelessness or lack of attention. This may occur in taking hydrometer readings if electrolyte is spilled, or if all of the electrolyte in the hydrometer syringe is not put back in the battery. Excessive gassing on charge also reduces the electrolyte level.

There is a certain loss of water from the electrolyte due to evaporation and gassing and this must be replaced at frequent intervals with pure water. Failure to do this is one of the causes of low electrolyte level. Low electrolyte level reduces the capacity of the battery and also causes hardening of the negative plates and sulphation.

Ignition Systems and Appliances.

168. Classification of Ignition Systems. Ignition systems may be classified as follows:

(*a*) Low-tension or make-and-break.
(*b*) High-tension or jump spark.
  1. Vibrating coil.
    (*a*) One coil with distributor.
  2. Master vibrator.
  3. Battery coil, non-vibrating.
  4. Magneto.
    (*a*) Wound armature type.
    (*b*) Non-wound armature type.

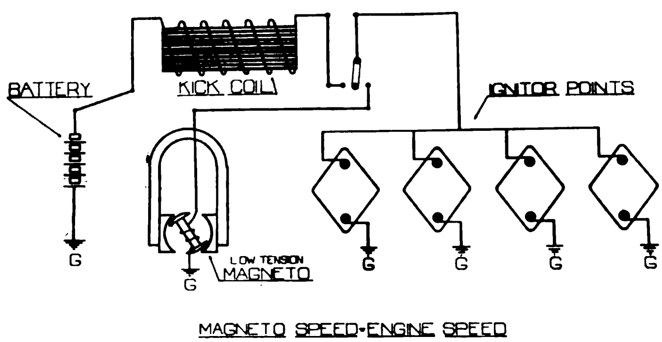

FIG. 228.—Low-tension make-and-break system.

Ignition systems may also be sub-divided according to another classification, namely, single, double and dual.

The aviation mechanic is interested more in the non-vibrating battery-coil and the magneto systems of the first classification than in any of the others.

The present ignition of the Liberty engine falls under the non-vibrating battery coil class, and most other airplane engines fall under the high-tension magneto class.

Single ignition employs only one plug per cylinder. Double ignition employs two plugs per cylinder, giving simultaneous sparks. Dual ignition consists of two independent systems, usually one for running and the other for starting. The usual combination is a vibrating coil system for easy starting, and a magneto system for running. Double

ignition has the advantage that, for the same throttle position, more speed and hence greater horsepower is obtained. Safety and reliability are also advantages of double ignition. The wiring diagram of a typical low-tension system is shown in Fig. 228.

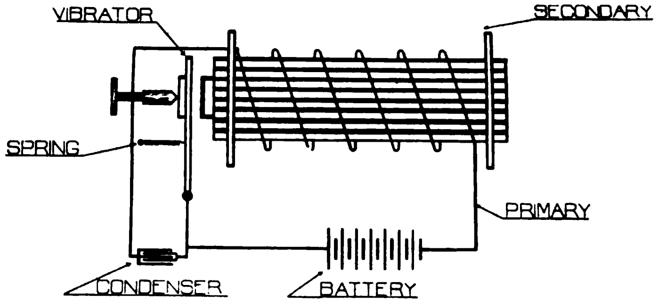

FIG. 229.—Vibrating coil.

Current, supplied from a battery or low-tension magneto, passes through a kick coil and through the ignitor points, when closed, to ground. The kick coil consists of a single winding of insulated copper wire on an iron core. When the ignitor points are opened the flow of current is interrupted and the energy stored up in the kick coil is discharged, giving

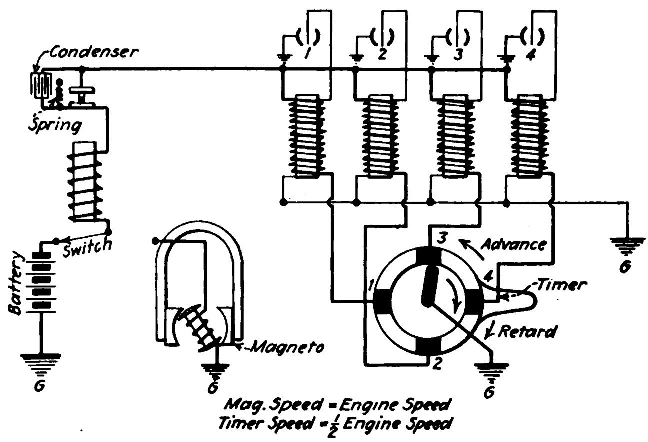

FIG. 230.—Vibrating coil system.

a spark across the ignitor points. The low-tension system is suitable only for slow speed, heavy duty engines. It has no application to aircraft engines.

The vibrating coil system employs a vibrating coil, a circuit diagram of which is shown in Fig. 229.

This coil consists of primary and secondary winding on an iron core.

Current flows from the battery across the vibrator points, through the primary winding to ground. The current flowing through the primary winding energizes the iron core, which attracts the vibrator. This opens

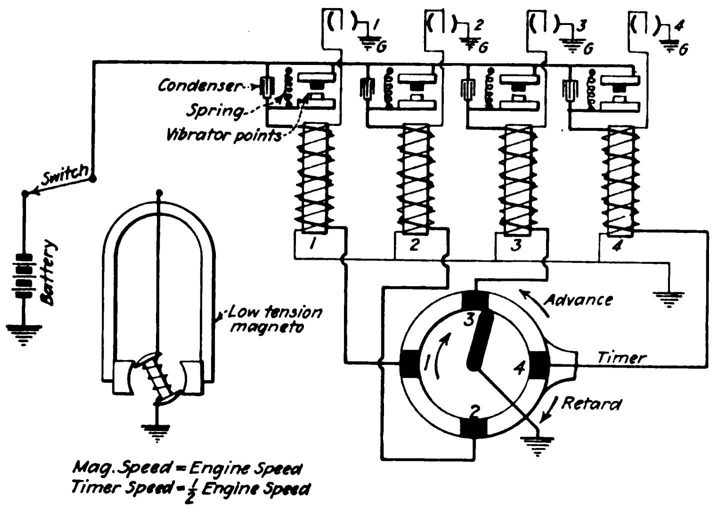

Fig. 231.—Master vibration coil system.

the vibrator points and interrupts the flow of the primary current. The resulting collapse of the magnetic field in the core induces a high voltage in the secondary winding which causes a spark to jump to secondary gap.

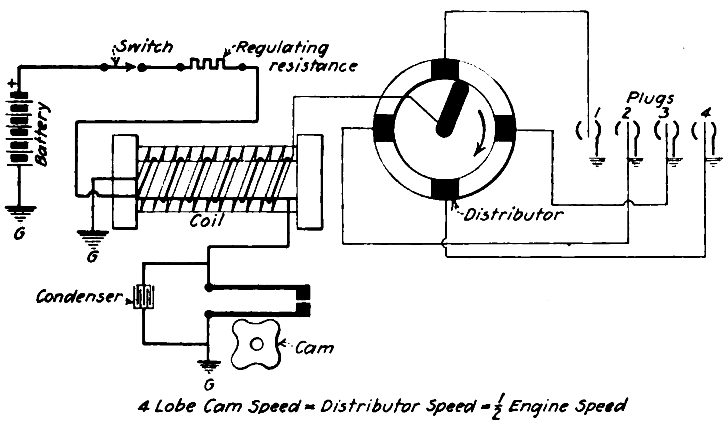

Fig. 232.—Non-vibrating battery coil system.

A circuit diagram of a vibrating coil system is shown in Fig. 230. There is one coil for each cylinder, and a timer, with one segment, connected to each coil. The circuit through any coil to ground is complete only when the rotating arm of the timer is in contact with the seg-

ment which is connected to that particular coil. All during the time that the rotating member is in contact with a segment, the corresponding coil is vibrating, thus producing a shower of sparks in the cylinder.

In the master vibrator system, shown in Fig. 231, there are as many non-vibrating coils as there are cylinders but only one vibrating coil. The latter contains only a primary winding and its purpose is solely to do the vibrating for the other coils. In other respects this system is the same as the vibrating coil system. Its advantage over the vibrating coil system is that while the latter requires that all vibrators be uniformly adjusted in order to obtain a uniform spark in all cylinders the master vibrator system has only one vibrator to be adjusted.

The non-vibrating battery coil system shown in Fig. 232, employs a mechanical device for interrupting the current instead of an electrically operated vibrator. Only one coil, of the non-vibrating type, is used. The high-tension current is conducted to the proper cylinder by means of a distributor, which is in the secondary circuit.

169. Function and Construction of Ignition Appliances. As the aviation mechanic is most interested in the battery coil and high-tension magneto systems, these will be taken up more in detail. Any ignition system of either of these two classes, must contain the following essential elements:

(*a*) *Source of Current.* This may be a battery, generator or magneto.

(*b*) *Coil.* This consists of an iron core and a primary and secondary winding. The core is usually made up of a bundle of soft iron wires. Over the core is wound the primary winding consisting of several hundred turns of insulated copper wire, No. 16 to No. 21 B. & S. gage. This is wrapped with some insulating material, such as empire cloth, and over this is wound the secondary winding. The latter is composed of several thousand turns of relatively fine copper wire, about No. 36 to 38 B. & S. gage, usually enameled. Between layers of the secondary, an insulating material such as paper, is placed. The whole coil is covered with insulating varnish or paraffin. It is important that the secondary winding be well insulated, owing to the high volage induced in it, which may be as much as 10,000 to 20,000 volts. One of the factors which determine the magnitude of the secondary voltage is the ratio of the number of turns of the secondary winding to the number of turns of the primary winding. That is, for a given number of turns on the primary, the greater the number of turns of the secondary, the higher will be the secondary voltage.

3. *Breaker Mechanism.* This consists of two breaker points, one stationary and the other located at one end of a pivoted breaker arm. The other end of the breaker arm carries a fiber rubbing-block. The breaker arm is actuated by a cam acting against the rubbing-block. The breaker points are usually made of an alloy, composed of about 80

per cent. platinum and 20 per cent. iridium. Platinum is used because it is non-oxidizing, has a high melting point and will withstand deterioration due to arcing, better than other metals. Iridium is added to increase the hardness. Pure tungsten which has a high melting point, is also used with success for breaker points.

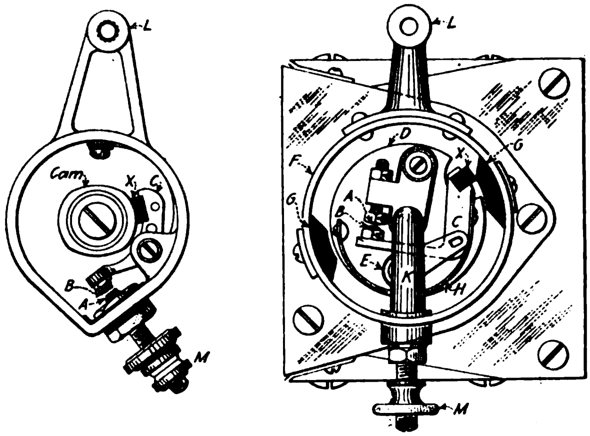

Fig. 233.—Two types of breaker mechanisms.

Two arrangements of cam and breaker points are found; one in which the points are mounted on a stationary base and the cam revolves, and the other in which the base on which the breaker points are mounted revolves and the cam is stationary.

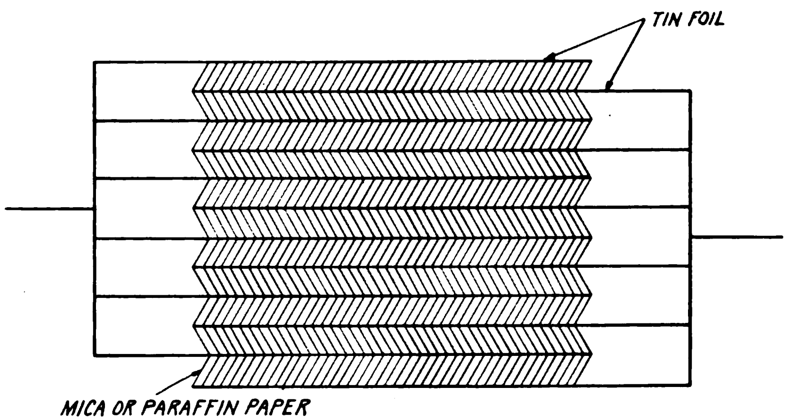

Fig. 234.—Elementary diagram of a condenser.

4. *Condenser.* The condenser is connected in parallel with the breaker points, that is, one terminal of the condenser is connected to the non-grounded breaker point and the other terminal to the ground. A condenser is made up of sheets of tinfoil with mica or paraffin paper between

them. All the odd numbered sheets of tinfoil are connected together and form one terminal of the condenser, and all the even numbered sheets are similarly connected and form the other terminal. There is no electrical connection between the two terminals of a condenser. A condenser will store up electricity but will not permit the passage of electric current through it. The purpose of the condenser is, first to reduce arcing at the breaker points and, second, to increase the intensity of the spark at the plug. The action of the condenser will be explained later.

5. *High-tension Distributing System.* This consists of the distributor and high-tension leads. There are many types of distributors but they all contain a rotating arm which is connected to one end of the secondary winding. As this arm revolves it makes contact in succession with metal segments connected to the different spark plugs. The distributor cap in which are mounted the metal segments, is made of insulating material such as bakelite or hard rubber. The current may be carried from the arm to the segment through a carbon brush which makes contact with the segment or there may be no actual contact, as in the gap type distributor, in which there is a small clearance between the end of the arm and the segment, the high-tension current being required to jump this gap to the segment.

For the secondary wiring, rubber covered copper wire is used. The insulation consists of a vulcanized rubber compound of quality and thickness that will stand 12,000 volts. Secondary cable is made in two sizes of overall diameter of 7 and 9 mm. respectively. The wire itself is stranded.

6. *Safety Spark Gap.* This device consists of two pieces of metal, set about 3/8 in. apart. One of them is connected to the end of the secondary winding and the other grounded. If the high-tension lead to a spark plug becomes disconnected, the current will jump across this gap to ground. If it were not for the safety spark gap, the high-tension current, in its efforts to escape to ground, might puncture the insulation of the coil.

170. Spark Plugs. A spark plug consists essentially of a steel shell, a central electrode and an insulator between the shell and the central electrode. Among the materials used for spark-plug insulators may be mentioned soapstone, glass, lava, mica and porcelain, the last two being the most common. Spark plugs may be divided into two classes according to whether they are made in one piece or demountable. In the demountable porcelain plugs, the porcelain is provided with a flange by which it may be clamped between a shoulder on the shell and a screw bushing. Copper asbestos or asbestos cord gaskets are placed between the porcelain and metal parts to insure a gas-tight joint.

In mica plugs, the insulation is made up of mica disks as shown in Fig. 236. Although mica is a very good insulator, this type of plug is open to the objection that oil is likely to be forced between the sheets of

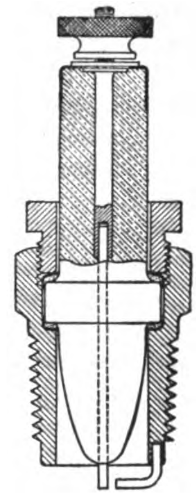

FIG. 235.—Porcelain spark plug.

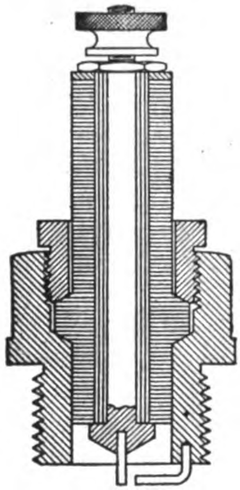

FIG. 236.—Mica spark plug.

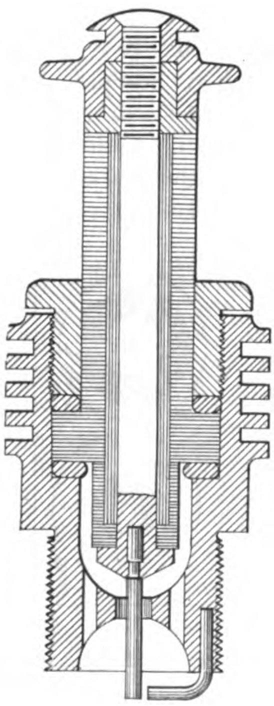

FIG. 237.—Special plug for airplane engines.

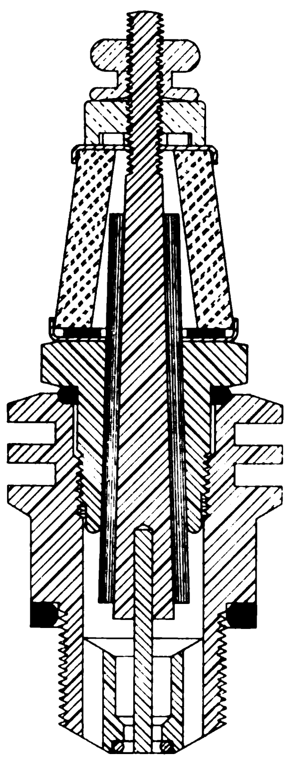

FIG. 238.—The Green Jacket plug.

mica and thus short-circuit the plug. Porcelain, on the other hand, although it makes a good gas and oil tight plug, is more liable to crack due to sudden changes in temperature.

The spark plugs in airplane engines work under more severe conditions than those of automobile engines, because of the high compression and the fact that airplane engines operate practically all the time under full open throttle. The problem of keeping the plug cool in an airplane engine is a difficult one. Special features of design are used for this purpose as, for example, having the shell finned. The plug shown in Fig. 237 is of this construction. In this type there is also a fin at the top of the stem to increase the radiation of heat from the stem and electrode.

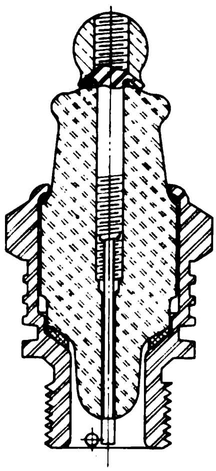

Fig. 239.—A. C. Titan airplane spark plug.

A good mica plug which has met with some favor in airplane practice is the Green Jacket plug, Fig. 238, manufactured by the Splitdorf Electrical Co. This is very much like the standard airplane type, described previously, with the exception that the plug is easily demountable and the mica is all laterally wound about the central electrode.

A porcelain plug which has proven very successful on the Liberty and Hispano-Suiza motors is the A.C. Titan shown in Fig. 239. The A.C. Titan is a one-piece or integral plug wherein the porcelain is sealed with a gas-tight joint, Fig. 239-*A*-6.

There are various types of electrodes on the market, some of the most common of which are illustrated in Fig. 240.

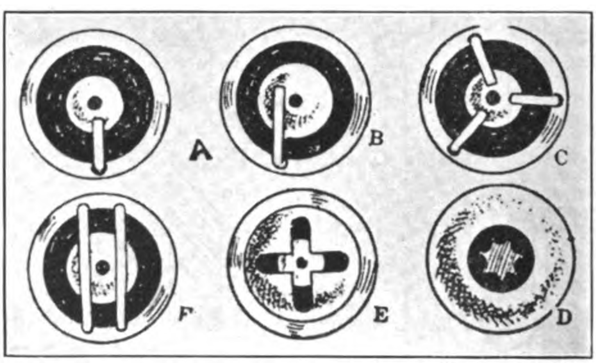

Fig. 240.—Types of spark-plug electrodes.

Types such as *C* are called multiple-point gaps. The advantage claimed for this construction is that if one gap widens due to the point heating and bending away, the spark will then jump across another point which forms the smallest gap. The life of the plug is thus lengthened.

The length of the spark-plug gap varies in different engines, depending upon the compression. The reason for this is that the size of the gap that a given voltage will jump depends upon the compression of the gas or air surrounding the gap. For example at 300° C. 3,500 volts will jump a 22 mm. gap in air, but under 90 lb. compression it requires about 15,000 volts to jump the same gap. Owing to the high compression used in airplane engine practice, the spark-plug gaps are small, ranging from about .013 in. to .023 in. It is important that this gap be adjusted accurately for any one engine to insure satisfactory engine performance. If the gap is too small, the heat due to the spark may be great enough to actually burn away the points. If the gap is too large, the engine may function properly at high speeds, but it will be very difficult to start and will misfire when accelerating under load.

There are three standard forms of thread for spark-plug shells. The S.A.E. standard is a straight thread 7/8 in. in diameter and having 18 threads to the inch. The metric standard has a straight thread 18 millimeters in diameter and a pitch of 1½ millimeters. The ½ in. standard pipe thread has 14 threads per inch and is slightly tapered.

171. General Principles Applying to Liberty Ignition System. The action taking place in an ignition coil of the non-vibrating type may be described as follows:

When the breaker points close, a current flows in the primary winding of the coil. When current flows in a conductor a magnetic field is set up around the conductor. Therefore the current flowing in the primary winding produces a magnetic field or flux in the core. When the breaker points open the primary current dies and the magnetic flux, which is due to the primary current, collapses. The collapse of the flux induces a voltage in the secondary winding. The magnitude of the secondary voltage depends upon two things, namely:

(*a*) The amount of the collapse of the flux; that is, the greater the collapse the greater will be the secondary voltage. For example, if a flux of 2,000,000 lines of force collapsed to zero, the voltage induced would be twice as large as if 1,000,000 lines collapsed to zero.

(*b*) The speed of the collapse. The greater the speed, the higher will be the voltage induced. For example, if a given flux collapsed in one second, the secondary voltage induced would be twice as great as if the collapse took place in two seconds.

Considering the first of these points, the amount of flux will depend upon the value of the primary current at the instant that the breaker points open. When the breaker points close the primary current does not reach its maximum value instantly, but it requires a certain time to build up. This building up of the primary current may be represented by the curve AB in Fig. 241.

The time interval required for the current to reach its approximate

maximum value may be only .002 or .003 sec. but this is an appreciable time when dealing with the operations in a high-speed engine. This time interval will vary according to the design of the coil. For example, in a coil constructed without an iron core Fig. 242-*A*, the current would

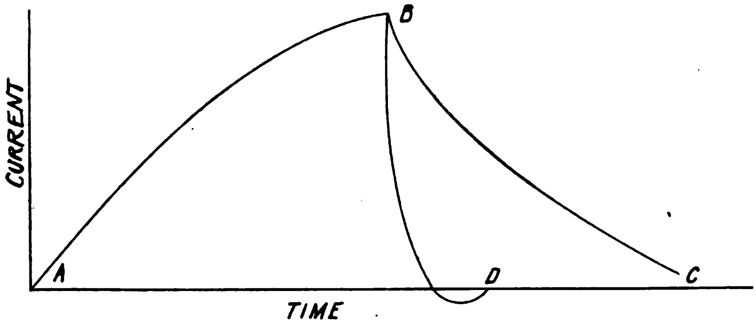

Fig. 241.—Current-time curve of a primary circuit.

build up very rapidly as shown by curve No. 1, Fig. 242. In a coil with an open core of iron, Fig. 242-*B*, the current would build up more slowly than in *A*, as illustrated by curve No. 2, Fig. 63. In a coil with a closed iron core, Fig. 242-*C*, the current would build up still more slowly curve

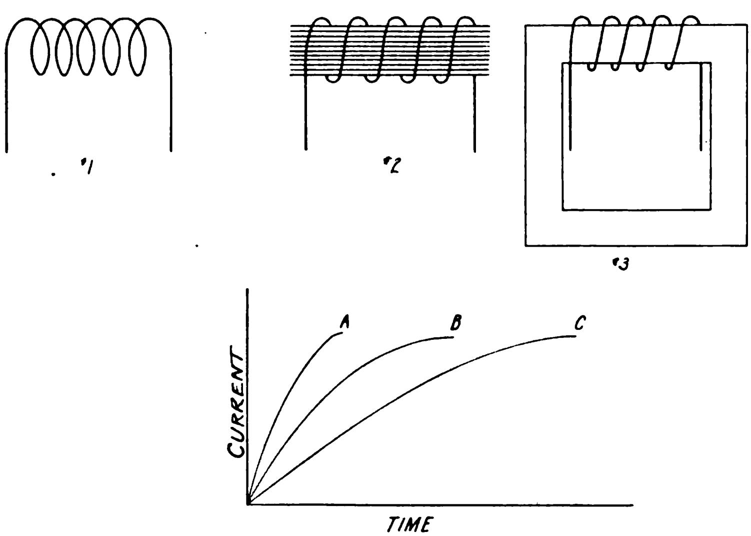

Fig. 242.—Effect of coil construction on building up of primary current.

No. 3, Fig. 242. It is therefore evident that in order to have maximum secondary voltage, the breaker points must remain closed a sufficient length of time to permit the primary current to build up to its approximate maximum value. This is a feature of the design of the cam.

Just as it takes time for the current to build up when the breaker points close, so it takes time for the current to fall to zero when the breaker points open. If there were no condenser in the circuit it would require exactly the same time for the current to fall as it did to build up as illustrated in Fig. 241, by the curve *BC*. When a condenser is connected across the breaker points, the energy which would otherwise be discharged across the breaker points when they open, flows into the condenser and charges it up. As the condenser becomes charged its voltage rises, and as this voltage is opposite in direction to the voltage induced in the primary winding, it tends to stop the flow of the current and causes it to fall to zero more rapidly and even to reverse it, so that it flows through the primary in the opposite direction. The net result of the action of the condenser is to cause the flux which is due to the primary current to collapse more rapidly and also to increase the amount of the collapse. This in turn increases the secondary voltage and hence the intensity of the spark at the plug.

Demonstrations During Study Period

(*a*) *Inductive Effects of a Kick Coil.* For this purpose a large kick coil of such resistance and current carrying capacity that it can be connected to a 110-volt D.C. line should be used. Two 110-volt incandescent lamps, in series with each other, are connected in parallel with the kick coil and line (see Fig. 243). When the switch is closed, it will be noted that the lamps do not come up to full brilliance instantly. This is due to the inductive effect of the kick coil, which tends to hold back the current, causing it to build up to its maximum value slowly. When the switch is opened the lamps will flash up brilliantly for an instant. This again is due to the inductive effect of the kick coil. When the current in the kick coil is suddenly interrupted the resulting collapse of the magnetic field in the core causes a high voltage to be induced in the winding, which high voltage is impressed across the lamps. If the switch is opened slowly so that an arc is drawn and the current dies gradually the lamps will not flare up, showing that when the flux collapses slowly a high voltage is not induced in the winding.

(*b*) *Transformer Action.* A copper ring is slipped over the upper extension of the core of the kick coil. When the switch is closed the ring will jump up several inches and then slowly settle back in place. This is due to the fact that when the switch is closed a magnetic field is built up in the core of the coil. The lines of force of this field cut the copper ring and induce a voltage in it. This voltage causes a current to flow in the ring, which in turn produces a magnetic field about the ring. The magnetic field of the ring and that of the core are opposite in direction, which causes the ring to be repelled. With the switch closed, if

the ring is moved up and down by hand on the core it will be found that considerable resistance is offered to the movement of the ring. This is due to the fact that when the ring is in motion it is cutting the lines of force of the magnetic field and a voltage is induced and current flows in the ring. The current in the ring produces a magnetic field about the ring which is always of such a direction as to resist the motion which produces it.

(c) *Effect of Condenser upon Primary and Secondary Circuits.* For this demonstration, an ordinary ignition coil of the vibrating type with a separate condenser is used. The coil is first operated with the condenser connected across the breaker points and the secondary spark gap adjusted to give the maximum steady spark. The vibrator should be adjusted to give the minimum sparking at the interrupter points. The condenser should then be disconnected and it will be noted that the sparking at the

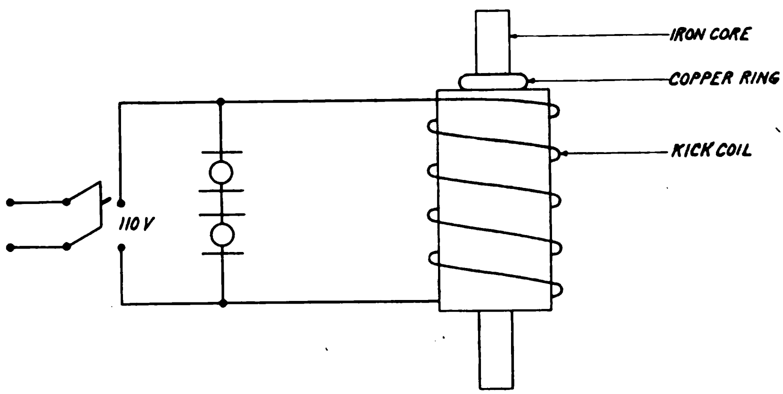

FIG. 243.—Connections for demonstration of inductive and transformer, effects of a kick coil.

interrupter points increases and the secondary spark becomes irregular or fails entirely. If the condenser is short-circuited the coil becomes inoperative.

Principles of High-tension Magnetos. (Aircraft Engine Type)

172. Wound-armature Type. A typical wound-armature type magneto must contain the following elements:

Magnets. The magnets are made of special chromium or tungsten steel, because of their high retentivity. They are U-shaped and their function is to provide a magnetic field.

Magnetic Path. The magnetic path is made up of the pole pieces and core, in addition to the magnets. The pole pieces are made of solid or laminated soft iron. The core is made of laminated soft iron, the reason being to reduce internal losses and heating.

Primary Winding. This usually consists of about 200 turns of No. 18 gage B and S, insulated copper wire, wound on the armature core. One end of the winding is grounded to the core and the other end is connected to the breaker mechanism.

Secondary Winding. The secondary winding consists of several thousand turns of No. 36 or No. 38 gage B and S, insulated wire wound over the primary winding. One end of the secondary is grounded to the core, and the other end is connected to the collector spool.

Interrupter Mechanism. This consists of the breaker point and cams. The breaker points are mounted on the breaker base which is keyed to the armature shaft and revolves with the armature. The cams are usually two in number and are mounted in the breaker housing. In some types of magnetos the cams are separate pieces and in others the cams are stamped into the breaker housing. The breaker housing is so mounted that it can be rocked a number of degrees, giving the advance and retard positions of timing.

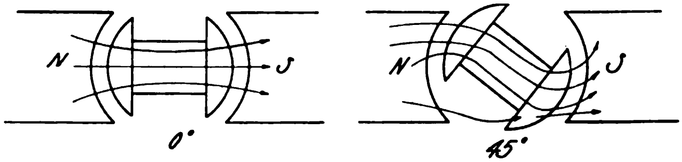

FIG. 244.—Magnetic path of a wound-armature magneto.

Condenser.—The condenser is constructed of tinfoil sheets separated by sheets of mica or oiled paper. One end of the condenser is grounded to the core and the other end connected to the nongrounded side of the breaker mechanism. The condenser revolves with the armature.

Distributor Mechanism. The distributor mechanism consists of: 1. Distributor rotor, one end of which is connected to the secondary winding and the other end distributes the high-tension current to the various segments. The distributor rotor is made from an insulating material such as bakelite or hard rubber and is mounted on the distributor gear. 2. The distributor block is made from bakelite or hard rubber and contains the segments and rotor brush track. The purpose of the distributor mechanism is to distribute the high-tension current to the plugs in the proper sequence.

Safety Spark Gap. This consists of two electrodes, one of which is connected to the ground and the other to the secondary winding. The electrodes are separated by an air gap of approximately ⅜ in. The safety gap as the name implies, is a safety device to protect the secondary winding in case any one of the secondary leads should become disconnected. The secondary current will then discharge through the safety gap, whereas, without the safety gap, it might break down the insulation of the secondary winding.

Grounding Switch. The function of the grounding switch is to short-circuit the interrupter points, thereby shutting down the engine.

The generation of voltage in the primary winding of a wound-armature type magneto depends upon the principle that, if the number of lines of force or flux passing through a coil is varied, that is, either increased or decreased, a voltage will be generated in the coil. In the magneto the flux of the magnet passes from the north to the south pole through the field pieces and core, and hence through the primary winding. As the armature is revolved, the number of lines of force passing through the primary winding changes, as will be explained in detail. The primary voltage on open-current, that is, with the primary circuit kept open all the time, will first be discussed. The position of the armature marked 0° in Fig. 245 will be considered first. In this position all of the flux passes through the core as indicated by the arrows. As the core moves a small distance from this position the path of the flux will not change, that is, all of it will continue to pass through the core and there will be no voltage generated. In the second position, Fig. 245, the armature

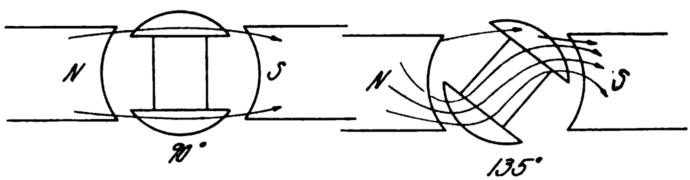

FIG. 245.—Path of flux in wound-armature magneto.

has moved through 45 degrees. As the armature approaches this position most of the lines of force will be distorted and will continue to pass through the core, because the reluctance of the iron of the core is less than that of air, and the flux tends to take the easiest path. But due to the fact that the flux is crowded into the upper left-hand pole tip, the latter becomes saturated, and some of the flux will leak from the lower left-hand pole tip directly across to the right-hand pole tip, and this part of the flux will no longer pass through the core. Hence, the number of lines passing through the core and primary winding will be slightly decreased, which will cause a small voltage to be generated in the primary winding. At the instant that the armature reaches the third or 90-degree position, all of the flux will pass directly across the ends of the core and hence none will pass through the center of the core and primary winding. Just before the armature reaches this position, the flux is entering the core at the upper end and leaving at the lower end, similar to the 45-degree position, and just after the armature passes the 90-degree position the flux enters the core at the lower end and leaves at the upper end, similar to the 135-degree position. Hence, as the armature passes through the 90-degree position the flux through the core decreases to zero and

then increases in the opposite direction, or in other words, reverses. In this position the flux is changing at the maximum rate and therefore the maximum voltage is generated. In the fourth position, or 135 degrees a similar condition exists to that of the 45-degree position and the value of the voltage will be the same as at 45 degrees. When the armature has moved through 180 degrees the same condition exists as at 0 degree and the voltage generated at this point is zero. During one-half revolution the primary voltage has varied from zero to a maximum and back to zero again. During the second half revolution, the action is the same except that the voltage generated is in the opposite direction, or negative, assuming that the voltage in the first half revolution is called positive.

Fig. 246 shows a typical open-circuit voltage wave for a wound armature type magneto.

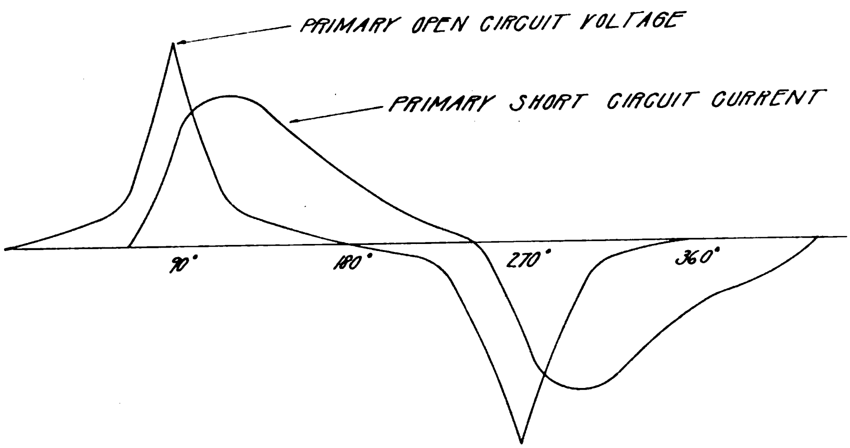

FIG. 246.—Open-circuit primary voltage and short-circuit primary current waves of a wound-armature type magneto.

It should be noted that the maximum point of the voltage wave corresponds to the 90-degree position of the armature, as previously explained. In all wound-armature magnetos the maximum voltage does not occur at exactly 90 degrees, the exact location of the point of maximum voltage depending on certain details of design. Generally speaking, however, this point may be said to be approximately 90 degrees.

If the interrupter points are closed, then, due to the primary voltage generated by the rotation of the armature, a current will flow in the primary winding. A typical example of a primary-current wave on short-circuit, that is, primary circuit closed all the time, is shown in Fig. 246. It should be noted that the peak of the primary short-circuit current wave does not occur at the same time as the peak of the primary open-circuit voltage wave, but after it. In other words, the primary

current lags behind the primary voltage. The amount of this lag varies in different magnetos and may be as much as 30 or 40 degrees.

When a current of electricity flows in a conductor, a magnetic field is set up around the conductor. Hence, when a current is flowing in the primary winding, a magnetic flux is set up in the armature core. The amount of flux is proportional to the strength of the primary current, that is, the greater the current, the greater is the flux. This flux is passing through the secondary winding. When the interrupter points open, the primary current dies and the flux, which is due to the primary current, collapses. This collapse of flux induces a voltage in the secondary winding. If the secondary circuit is complete and the secondary

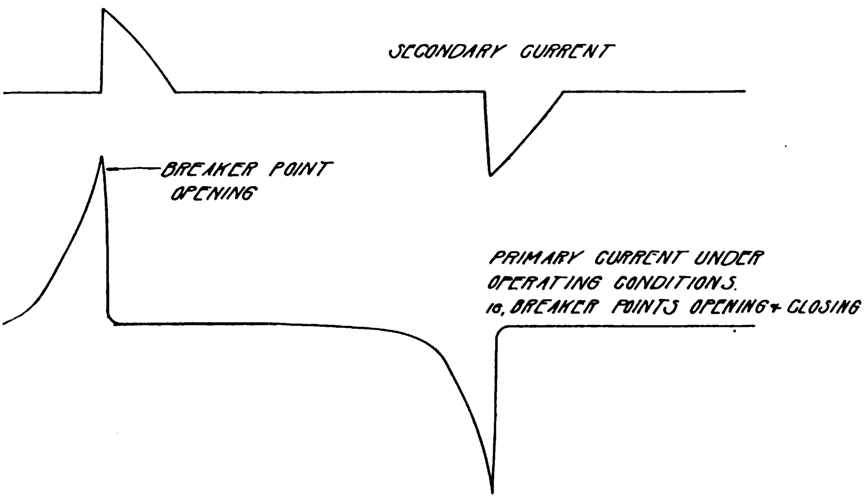

Fig. 247.—Primary and secondary-current waves of a wound-armature magneto under operating conditions.

voltage is high enough to jump the spark-plug gap a secondary current will flow. The magnitude of the secondary voltage depends upon the amount of the collapse of the flux which, in turn, depends upon the value of the primary current at the instant that the points open. It is evident, therefore, that in order to get the maximum secondary voltage and, hence, the maximum intensity of spark, the interrupter points must open when the primary current is at a maximum. The proper time for the interrupter points to open cannot be determined from the short-circuit current wave, because it is found that the maximum primary current under operating conditions, that is, breaker points opening and closing, does not occur at the same time as the maximum primary current on short-circuit. As stated before, the maximum short-circuit current may occur as late as 30 or 40 degrees after the 90-degree position, while it is usually found that the maximum primary current under operating

conditions is obtained when the breaker points open a few degrees beyond the 90-degree position, for example, about 96 degrees.

Fig. 247 shows typical waves of secondary current and primary current under operating conditions.

In the wound-armature type magneto, the relation between the position of the armature and the pole pieces, at the instant the breaker points open, is fixed by the manufacturer, through the fact that the breaker base is keyed to the armature shaft. This relation cannot be changed. If the interrupter opening is set to give the maximum spark on full advance, then the interrupter points will open with the armature in approximately the position shown in Fig. 248-*A*, or approximately at 96 degrees and 276 degrees, which is the point where the primary current is at its maximum value. In the retard position of the timing lever, the breaker points will open when the armature is in some such position as that shown in Fig. 248-*B*. In this position the primary current is not

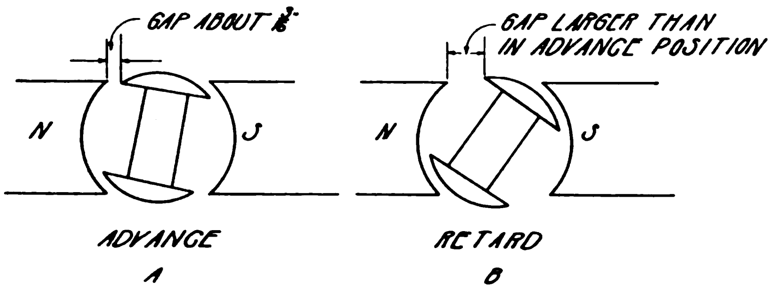

Fig. 248.—Relation of armature to pole pieces for advance and retard positions of timing lever, wound-armature magneto.

at its maximum, and the secondary spark is weaker. Therefore in a wound-armature type magneto, the maximum intensity of spark is obtained at only one position of the timing lever.

173. Non-wound Armature Type. A typical non-wound armature type magneto must contain the following elements:

Magnets. The material and construction of the magnets are similar to a wound-armature type. The magnets do not straddle the shaft but are located as shown in Fig. 249.

Magnetic Path. The magnetic path consists of the rotor wings, field pieces and core, in addition to the magnets. The rotor wings, 2, 4, or 6 in number, are made of mild steel. Each rotor wing always remains of the same polarity. The north rotor wings are separated from the south rotor wings by a non-magnetic material, Fig. 249-*B*, such as bronze. The rotor wings are mounted on the shaft and revolve with it. The field pieces are made of laminated soft iron. The cradle is made of non-magnetic material and is cast around the field pieces.

The core is also made of laminated soft iron, and is held on to the field pieces by clamps. The field pieces and core do not revolve.

Primary Winding. This is similar in size of wire and number of turns to the primary of a wound-armature type. It is wound on the core which is stationary.

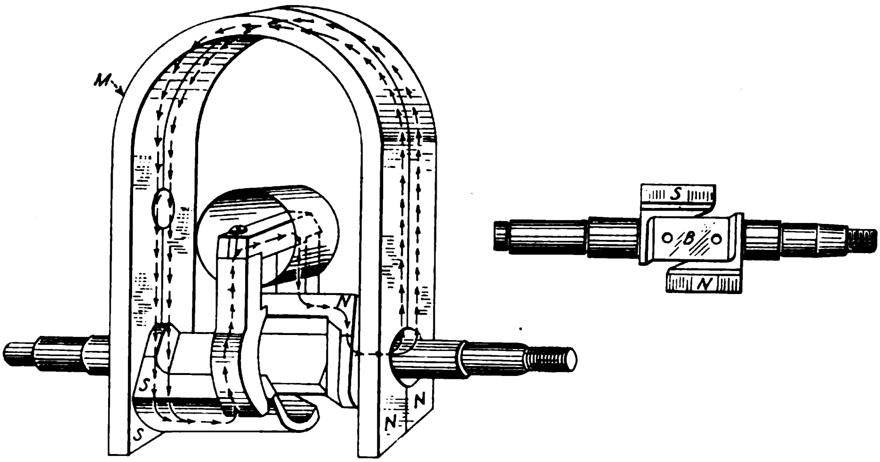

FIG. 249.—Magnetic path of a non-wound armature magneto.

Secondary Winding. This is similar to the wound-armature type, except that it does not revolve. One end of the secondary is fastened to the collector segment, a brass insert in one side of the coil.

Interrupter Mechanism. This consists of the breaker points and cam. The breaker points are mounted on the breaker base assembly which

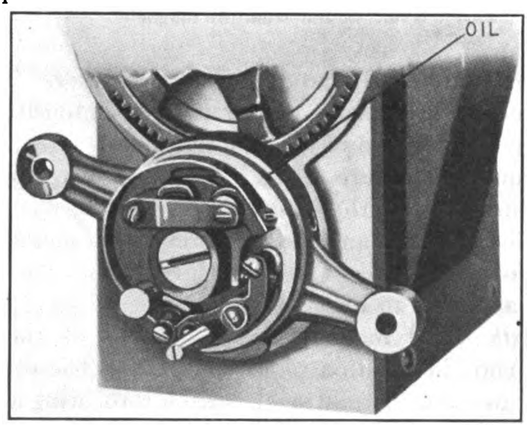

FIG. 250.—Breaker mechanism, Dixie magneto.

in turn is mounted on the magneto cradle. The cam is keyed to the armature shaft and, unlike the wound-armature type, the cam revolves while the breaker points are stationary.

The Condenser. The construction of the condenser is similar to a wound-armature type. The condenser does not revolve with the armature or rotor.

The remaining parts, namely, the distributor, safety gap and grounding switch, are the same in function and similar in construction to the corresponding parts of the wound-armature type.

In considering the method by which voltage is generated in the non-wound armature type magneto, it must be borne in mind that the rotor wings are separated by non-magnetic material. Therefore, practically no flux can pass directly from the north to the south rotor wing, but it must take the path through the field pieces and core. The generation of voltage in the primary winding depends upon the principle that if the

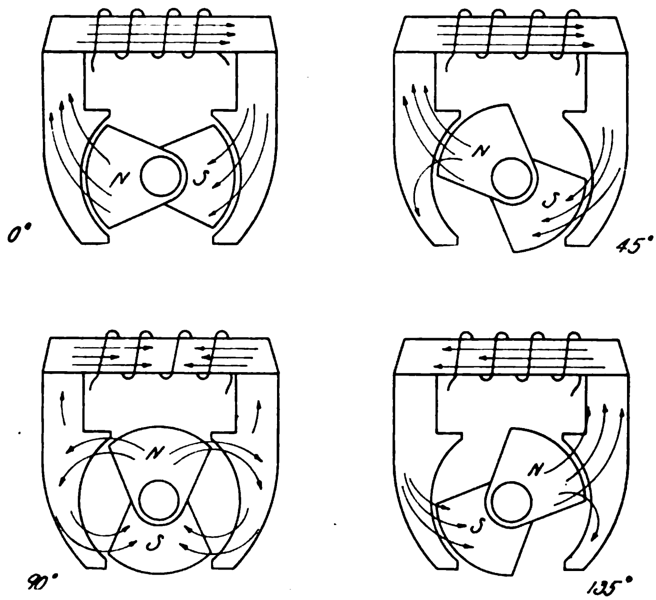

Fig. 251.—Path of flux in non-wound armature magneto.

number of lines of force or flux passing through a coil is varied, that is, either increased or decreased, a voltage will be generated in the coil.

In the magneto, the flux of the magnets pass from the north rotor wing, Fig. 251, to one field piece, through the core and coil, to the opposite field piece and thence to the south rotor wing. As the rotor is revolved, the number of lines of force passing through the primary winding changes, as will be explained in detail. The primary voltage on open-circuit, that is, with the primary circuit kept open all the time, will be discussed first. When the rotor is in the 0-degree position, Fig. 251, all of the flux passes through the core as indicated by the arrows. As the rotor moves a small distance from this position the path of the flux will not change;

all of it will continue to pass through the core and there will be no voltage generated. In the second position, Fig. 251, the rotor has moved through 45 degrees. As the rotor approaches this position most of the lines of force will be distorted and will continue to pass through the core, because the reluctance of the iron of the core is less than air and the flux tends to take the easiest path. But due to the fact that the flux is crowded into the upper left-hand and lower right-hand edges of the field pieces they become saturated and some of the flux will begin to leak from the north rotor wing, through the field piece to the south rotor wing. This part of the flux will no longer pass through the core; hence, the number of lines of force passing through the core and primary winding will be slightly decreased, causing a small voltage to be generated in the primary winding. At the instant that the rotor reaches the third position or 90 degrees, Fig. 251, all the flux will pass from the north to the south rotor wing through the field pieces. In other words, the rotor wings may be said to be magnetically short-circuited. Hence, in this position there will be no flux through the core. Just before the rotor reaches this position, the flux is passing through the core from left to right as in the 45-degree position, and just after the armature has passed the 90-degree position the flux is passing through the core from right to left, similar to the 135-degree position. Hence, as the rotor passes through the 90-degree position, the flux through the core decreases to zero and then increases in the opposite direction, or in other words reverses. Consequently, in this position the flux is changing at the maximum rate and the maximum voltage is generated.

In the fourth position, Fig. 251, 135 degrees, a similar condition exists to that of the 45-degree position, and the value of the voltage will be the same as at 45 degrees. When the armature has moved through 180 degrees the same condition exists as at 0 degrees, and the voltage generated at this point is zero. During one-half revolution the primary voltage has varied from zero to a maximum and back to zero again. During the second half revolution the action is the same except that the voltage generated is in the opposite direction or negative; assuming that the voltage in the first half revolution is called positive.

The primary open-circuit voltage wave, the primary short-circuit current wave and the secondary-current wave for a non-wound armature type magneto are all similar, in a general way, to the corresponding waves of a wound-armature type magneto. In some cases the lag of the primary short-circuit current behind the primary open-circuit voltage is greater than on the wound-armature type, but the maximum primary current under operating conditions occurs a few degrees after 90 degrees as in the wound-armature type.

The explanation of the induction of the secondary voltage as previously given for the wound-armature type holds equally well for the non-wound type.

In the non-wound armature type magneto the relation between the position of the rotor and the field pieces, at the point of interrupter opening is not affected by a change in the position of the timing lever, as the coil, field pieces and breaker mechanism are so mounted on a cradle that the whole assembly moves with the timing lever, (see Fig. 252).

Hence the same intensity of secondary spark is obtained in any position of advance or retard, due to the fact that the primary current is always broken at the point of maximum value.

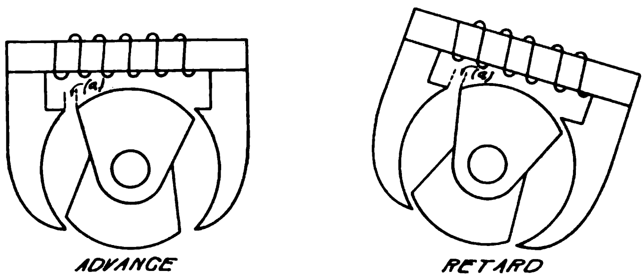

FIG. 252.—Advance and retard position of armature, and field pieces, non-wound armature magneto.

174. Speed Relations. The wound-armature type magneto produces only two sparks during each revolution of the armature. Once during each half revolution of the armature the primary circuit is interrupted, thereby producing one secondary spark each half revolution of the armature, or two secondary sparks during each revolution. The speed relation can best be explained by an example. An 8-cylinder 4-cycle engine requires eight sparks in two revolutions of the crankshaft, or four sparks in one revolution of crankshaft. A wound-armature type magneto produces two sparks in one revolution of the armature shaft. Therefore, the armature shaft speed must be twice the engine crankshaft speed. The distributor speed will be one-half crankshaft speed and one-fourth magneto-shaft speed.

For different numbers of cylinders the gear ratio will be different, as indicated in the following table:

TABLE XIX.—MAGNETO, ARMATURE AND DISTRIBUTOR SPEEDS

No of cyl.	Magneto armature speed vs. engine speed	Distributor speed vs. magneto armature speed
4	Magneto armature speed = engine speed.	Distributor speed = $\frac{1}{2}$ magneto armature speed.
6	Magneto armature speed = $1\frac{1}{2} \times$ engine speed.	Distributor speed = $\frac{1}{3}$ magneto armature speed.
8	Magneto armature speed = $2 \times$ engine speed.	Distributor speed = $\frac{1}{4}$ magneto armature speed.
12	Magneto armature speed = $3 \times$ engine speed.	Distributor speed = $\frac{1}{6}$ magneto armature speed.

Distributor gear speed is always one-half the crankshaft speed on a 4-cycle motor.

In the non-wound armature type, the number of rotor wings determines the number of sparks that can be obtained in one revolution of the armature. The number of lobes on the cam, however, determines the number of sparks actually produced in one revolution of the armature. In the various models of the Dixie magneto will be found several combinations of rotor wings and cam lobes, ranging from two to six rotor wings with an equal or less number of cam lobes. Thus, a 4-wing rotor with a 4-lobe cam will give four sparks per revolution, but the same rotor with a 2-lobe cam will give only two sparks per revolution. Data on the number of rotor wings and cam lobes and the speed relations of some of the most common models of Dixie magnetos are given in the following table:

Table XX.—Speed Relations for Various Models of Dixie Magnetos

Model	Cyl.	Rotor wings	Cam lobes	Magneto speed vs. engine speed	Distributor speed vs. magneto speed
481	4	4	2	Magneto speed = engine speed.	Distributor speed = ½ magneto speed.
612	6	4	2	Magneto speed = 1½ engine speed.	Distributor speed = ⅓ magneto speed.
800	8	4	4	Magneto speed = engine speed.	Distributor speed = ½ magneto speed.
1260	12	6	6	Magneto speed = engine speed.	Distributor speed = ½ magneto speed.
1240	12	6	4	Magneto speed = 1½ engine speed.	Distributor speed = ⅓ magneto speed.

The distributor speed will always be one-half engine crankshaft speed for a 4-cycle engine. The number of revolutions of the armature to one revolution of the crankshaft may be determined from the following:

$$\frac{\frac{1}{2}\text{ number of cylinders}}{\text{number of lobes on cam}} = \text{number of revolutions of armature shaft}$$

to one revolution of crankshaft.

175. Adjustments. The adjustments necessary on the wound-armature type magneto include the following:

Gap between the Armature Edge and the Pole. The relation of the armature to the pole pieces at the point of interrupter opening is fixed by the manufacturer through the fact that the breaker base is keyed to the shaft. This adjustment cannot be changed (see Fig. 248).

Breaker Point Opening. This varies in different types. Some examples are: Bosch, .016 to .020 in.; Berling, .016 to .020 in.; Simms, .018 in.

Safety Spark Gap. This is usually constructed so that there is very little likelihood of it getting out of adjustment. In airplane models, it is about 3/8 in.

Distributor Gear Setting. The distributor brush should be fully on the segment when the timing lever is in full advance, as shown in

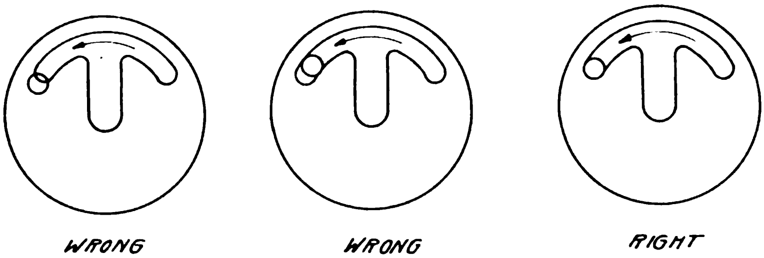

Fig. 253.—Distributor brush position on full advance.

Fig. 253. An allowance of 3/64 in. either way is permissible in the setting of the distributor brush. For the purpose of setting the distributor gear, there is a punch mark on the distributor gear and one on the distributor pinion. These punch marks should be lined up. In some cases the distributor gear contains two punch marks, lettered *C* and *A* (clockwise and anti-clockwise), respectively, or *R* and *L* (right and

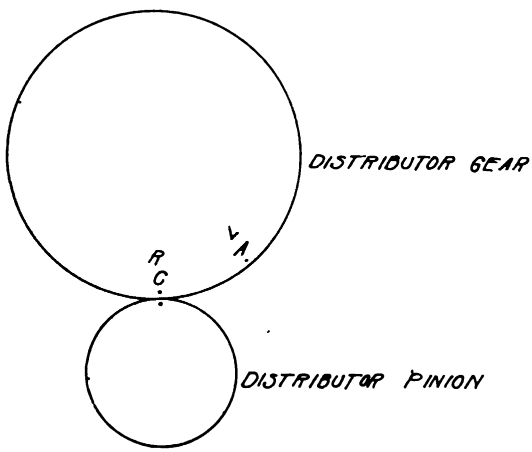

Fig. 254.—Method of setting distributor gear.

left). The proper mark should be used according to the direction of rotation of the magneto, Fig. 254.

The adjustments necessary on the non-wound armature type magneto include the following:

Rotor Wing Gap. The relation between the rotor and the field pieces at the point of interrupter opening is adjustable, as shown in

Fig. 252. For most models of the Dixie, the rotor wing gap is .015 to .035 in. In the Dixie 800 this adjustment is .050 to .075 in.

Breaker Point Opening. This adjustment is .018 to .022 in.

Safety Spark Gap. In some models the safety spark gap may be thrown out of adjustment due to bending of one of the points, in which case it should be reset at 3/8 in.

Distributor Gear Setting. This is the same as for the wound-armature type.

A magneto is designed to operate only in one direction. If it is desired to operate it in the reverse direction of rotation the following changes must be made. In the wound-armature type the breaker mechanism must be replaced by a new one, and the distributor gear must be reset according to the other punch mark, as previously explained.

In the non-wound armature type, the cam must be changed, either by replacing or in some models by reversing it. In some models the breaker mechanism must also be replaced. The distributor gear setting must be changed.

176. Care of Magnetos. One of the greatest sources of trouble with magnetos is too much oil. For general lubrication about 10 drops of a clean, light oil about every 25 hr. of use is sufficient. Oil should not be put in the breaker box or on the distributor. The distributor should be frequently cleaned of any carbon deposit by wiping it with a rag moistened with gasoline. The cams may be lubricated with a thin film of vaseline. Particular care should be taken that no oil or vaseline comes in contact with the breaker points. The breaker-point contacts must be smooth and if there is any evidence of pitting of the surfaces, they should be smoothed with a fine file. All carbon brushes should be inspected to see that they have the proper spring tension and are making good contact with their rubbing surfaces.

177. Ordering of Parts. In ordering parts for a magneto, if a trade catalogue is not available and the part numbers cannot be given, the following information should be specified:

Name of magneto.	Example, Dixie.
Model.	Example, 800.
Rotation.	R. H. or L. H.
Spark.	Fixed or variable.
Timing lever.	R. H. or L. H. or both.
Engine used on.	

Liberty Generator-battery Ignition System

178. Purpose and Elements. The Liberty engine employs two separate sets of spark plugs, one in the rear end and one in the front end of each cylinder. The ignition system must provide either single ignition

on either set of plugs, or double ignition, giving two simultaneous sparks in each cylinder. The system must also provide a good spark for starting. The Liberty ignition accomplishes this by means of a switching arrangement through which the battery supplies the current for single ignition, starting on either set of plugs. When running on double ignition the generator supplies the ignition current and also charges the battery. The switching arrangement is such that double ignition must not be used below an engine speed of 750 r.p.m. Running on double ignition below 750 r.p.m. would cause the battery to pump back through the generator, since the voltage of the latter would be below that of the battery.

The ammeter provides an easy method for locating trouble in the primary circuit when the engine is at rest, and is the pilot's guide regarding the proper functioning of the ignition system. Knowing the normal primary current when the engine is at standstill, any variation from this normal current immediately warns the pilot of some trouble in the primary circuit. When operating, the ammeter shows the condition of the battery, provided the system as a whole is in proper adjustment. The ammeter likewise shows whether the generator is functioning properly.

The system has been very successful to date, and no part has been found to be weak, either mechanically or fundamentally. Only a few slight changes have been made since the original design.

In order to provide the requirements of an ignition system for the Liberty engine as stated above, the elements necessary were a generator, a regulator, a battery, an ignition switch and two distributor heads. The battery has been covered elsewhere and will not be discussed here.

The approximate weights of the various parts are as given in the following list:

Generator	11¼ lb.
Voltage regulator	1½ lb.
Switch	1 lb.
Storage battery	10¼ lb.
Two distributor heads	11 lb.
Total weight exclusive of spark plugs, low-tension leads, high-tension cables and high-tension manifold is	35 lb.

179. Generator. The function of the generator, as before stated, is to charge the battery and to supply ignition current when running on double ignition.

It is a 4-pole shunt generator and has no interpoles. The armature is wave or series wound. With a wave-wound generator only two brushes, 180 electrical degrees apart on the commutator, are required to collect the current. The Liberty generator employs four brushes for reliability. In case one brush should not be making contact with the commutator

for any reason, there would still be one brush, of the same polarity on the opposite side of the commutator, to collect the current. Again, due to possible chattering of the brushes, arcing would occur when one of two brushes left the commutator. By using four brushes this arcing is eliminated, for each brush is of sufficient cross-section to carry the full-load current of the generator. The generator is geared to run at 1½ times crankshaft speed.

The generator has no definite rating. Since it is designed to supply current for double ignition, and at the same time charge the battery, the current delivered by it will vary from as much as 15 amp. to about 3 amp., depending upon the condition of the battery, as previously discussed in detail. The design is such, however, that the generator will carry a load current of 5 amp. continuously, without overheating the armature which is impregnated in sterling varnish to give good insulating properties.

The generator itself has only one bearing, which is at the top of the machine. It is a thrust and radial ball bearing and carries the weight of the armature, and its lubrication is important. When the generator is assembled, the top bearing should be packed with grease mixed with flake graphite. During operation the generator bearing should be oiled through the hole in the top of the generator-end housing. The bearing receives the oil by the drip from a felt wick. In lubricating it is important to see that no oil reaches the commutator. The lower bearing is really the generator driveshaft bearing and is situated in the engine itself. It is a radial bearing.

The generator speed is always 1½ times engine speed, and since the latter may reach 2,000 r.p.m., the generator speed may vary from 600 or less to 3,000 r.p.m., or in the ratio of 5 to 1. Thus, if the generator gave a voltage of 10 volts at 600 r.p.m., it would, at the same field current, give a voltage of 50 volts at 3,000 r.p.m. This shows the necessity of controlling the generator voltage by means of a regulator.

180. Voltage Regulator. The function of the regulator, as explained above, is to maintain a constant generator-terminal voltage, regardless of the speed. The reasons for choosing a voltage regulator in preference to any of the other methods of voltage control have been previously stated and discussed.

Referring to Fig. 255, the elements of the Liberty regulator are: (1) a soft-iron core, (2) a voltage coil, (3) a reverse coil, (4) a non-inductive resistance, (5) a set of contact points, and (6) a spring.

The operation of the Liberty vibrating regulator has been previously discussed in more or less detail. When the generator voltage falls to below 10 volts, current flows from the positive armature terminal of the generator through the voltage coil 2 in Fig. 255 to ground. Hence the voltage across the voltage coil is the same as the voltage across the

generator. Current also flows from the positive terminal of the armature, through the field coils to the regulator terminal marked "GEN. FIELD." From here it has three paths: (*a*), through the reverse coil 3, (*b*), through the non-inductive resistance 4, and (*c*), through the contact points 5, since the latter are closed when the generator voltage is below 10 volts. The resistance of the path through the contact points is practically zero, while the resistance of the paths through the reverse coil and non-inductive resistance is high, and therefore practically all the current will flow through the contact points to ground. Under these conditions there is maximum generator-field current, as the resistance in the field circuit is a minimum.

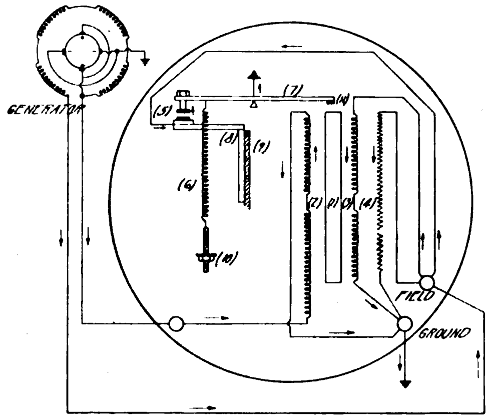

FIG. 255.—Liberty voltage regulator. Arrangement of elements and diagram of connections.

When the generator voltage reaches 10 volts the magnetic pull of the core, due to the current in the voltage coil, is great enough to overcome the reluctance of the air gap and the pull of the spring, thus opening the contact points. The field current must now all go through the reverse coil or the non-inductive resistance. Resistance has been added to the field circuit, and the field current and generator-terminal voltage fall. The reverse coil is wound in the same direction as the voltage coil, but current flows through it in the opposite direction. Thus, the reverse coil partially demagnetizes the core. The resulting decreased magnetic pull will not be sufficient to hold the armature against the opposing tension of the spring, and the contacts will close. The non-inductive resistance adds resistance to the field circuit when the contacts open and also absorbs the energy which would otherwise cause a spark at the contacts. In this respect the non-inductive resistance performs the function of a condenser.

The distance between the contact points is adjustable and should be from .005 to .007 in., preferably .006 in. This adjustment affects

the voltage at which they open, for the air gap at the core is equal to the gap at the points. The greater the gap at the points the higher the generator-terminal voltage when the points open. The fixed contact is insulated from the regulator frame by means of a strip of insulation under the contact clip. This is shown hatched in Fig. 255.

The spring tension, which is also adjustable, affects both the opening and closing of the contact points. The greater the spring tension, the higher the voltage at which the contact points open and close. This is the only adjustment affecting the closing of the points. The adjustment is made by means of the knurled nut shown in Fig. 255.

The adjustment of the regulator is a bench job. The generator and regulator are connected together as in normal operation, the specified cable and lugs being used. Then the generator is driven with no load at 3,000 r.p.m. The contact gap is adjusted to from .005 to .007 in. and

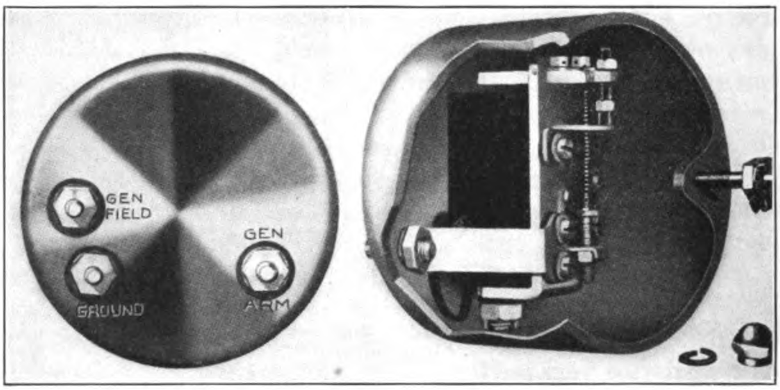

FIG. 256.—Liberty voltage regulator.

the spring tension is then adjusted until the generator voltage is 10.0 volts.

Fig. 256 shows the Liberty regulator complete, as assembled, front view and side view, the latter showing part of the aluminum regulator housing cut-away.

181. Switch Assembly. The ignition switch must provide for running single ignition on either set of plugs or for running double ignition. It must be so designed that it can be easily operated with a gloved hand.

The frame of the switch assembly is made of black bakelite, as bakelite is a good insulator, easy to mold, and mechanically strong. The outside face of the assembly is made of sheet metal, the switches of aluminum and the contact fingers of phosphor bronze. Two views of this switch are shown in Fig. 257.

The ammeter, which is deflected to the left on discharge and to the right on charge, is shown in Fig. 257. The terminal posts, to which the

cable terminals are fastened, can be plainly seen in the rear view of the switch assembly, which also shows the spirally wound resistance coils connected in series with the switch.

The circuit diagram showing the switch connected to the generator, battery and left distributor head assembly are shown in Fig. 258.

Assume the left-hand switch to be in the *on* position, that is, with the switch handle turned outward. The connections of the switch contact arms will be shown as in dotted lines in Fig. 258. Since the contact arms on the left-hand switch are insulated from each other, no current can flow to the switch from the generator. Under these conditions all ignition current must come from the battery. Starting from the positive terminal of the battery, current will flow to the battery terminal

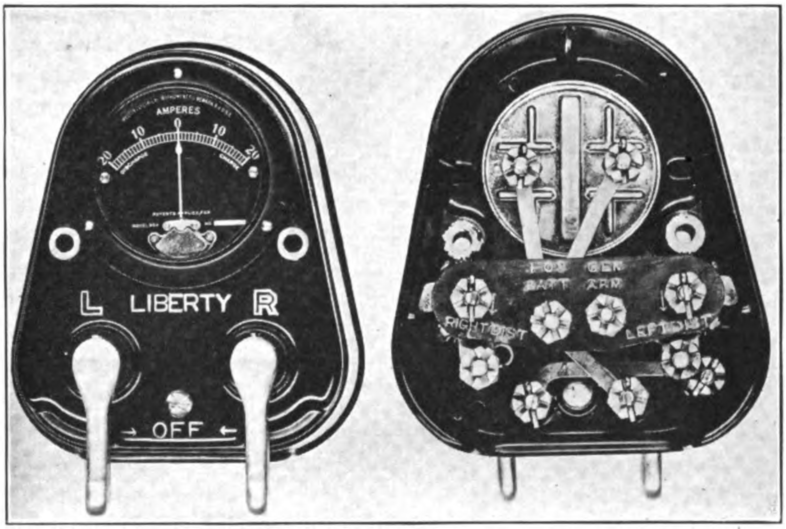

FIG. 257.—Liberty ignition switch assembly.

on the switch, through the ammeter, which will read discharge, to the upper left-hand button on the right-hand switch. From here it flows to the lower right-hand button on the left-hand switch, through the contact arm to the upper left-hand button on this switch, through the 1-ohm advance metal resistance coil to the primary winding in the left-hand distributor-head assembly. From here it flows across the breaker points to ground. The advance metal resistance serves to limit the current flow when the switch is left in the *on* position while the engine is at standstill, and thus protects the coil from injury due to overheating.

In the event that only the right-hand switch is in the *on* position, current will flow from the battery through the ammeter as before, across the contact arms of the right-hand switch, and from there through the 1-ohm resistance and right-hand distributor-head assembly, to ground. The

contact fingers of the right-hand switch as shown are connected together and the lower right-hand button does not serve as a terminal, but only as a support for the switch finger.

If both switches are in the *on* position, current flows from the positive terminal of the generator to the upper right-hand button of the left-hand switch. From the upper right-hand button of the left-hand switch the current flows to the lower left-hand button of this switch, then to the lower left-hand button of the right-hand switch. Here it divides through the

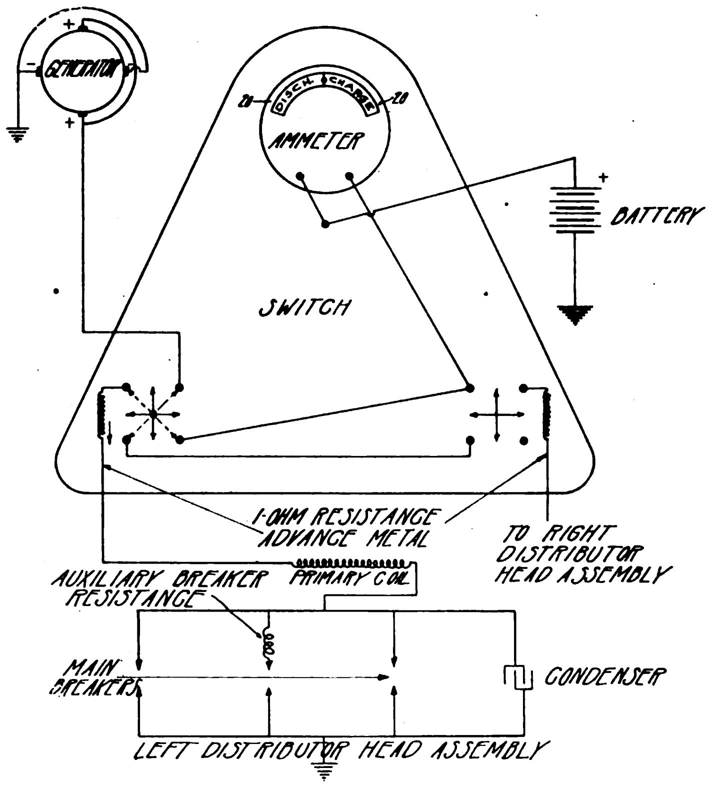

Fig. 258.—Diagram of connections of Liberty switch, front view.

contact arms, part passing to the right distributor-head assembly, part through the ammeter to battery to ground, and part to the lower right-hand button of the left switch through the contact arm to the left-hand distributor head assembly. The ammeter will show the rate at which the battery is being charged, which will depend upon the generator voltage and the condition of the battery. By looking over the circuits for either switch connected alone, it will be seen that the generator is not connected in either case; in other words, both switches must be in the *on* position before the generator is connected.

The first precaution in regard to operation of the ignition switch was stated previously; namely, that the switch must not be set on double ignition below an engine speed of 750 r.p.m. If double ignition is used below this speed, the battery voltage, which will be greater than the terminal voltage of the generator, will send current through the generator in the reverse direction and run it as a motor. The result will be a rapid discharge of the battery.

The second precaution is: *never leave switch in the on position while the engine is at standstill.* Under these conditions the battery would discharge through the breaker points to the ground if the points happened to be closed. A 1-ohm resistance is placed in series with each switch circuit, as before stated, in order to limit the current flow should either switch be left on. Nevertheless, this resistance will not prevent complete discharge of the battery.

182. Distributor Assemblies. The distributor assembly consists of the distributor head assembly, the distributor cup assembly and the adapter base.

Distributor Head Assembly. The distributor head is made of bakelite, which is an insulating compound. This compound is a product of the Dayton Engineering Laboratories and is made by the interaction of carbolic acid and formaldehyde. Wood pulp is added to increase the strength and dye to give the desired color. It is a good insulating compound, withstands hard usage, is not brittle and is easily molded into any desired shape. The entire distributor heads, excepting the rotor tracks, are made of this material. The rotor tracks, one in each head, are made of hard rubber.

In the distributor head there is a coil assembly which supplies the secondary voltage. The coil assembly consists of an iron core about which are wound, first, a primary and then a secondary winding, the adjacent layers of which are insulated from each other by means of insulating paper. Through the rotating high-tension brush situated in the distributor cup the secondary voltage is carried to the rotor track. From here connection is made to the proper spark-plug cable through a brass contact, connected to the distributor head spark-plug cable terminals. The details of the distributor head will be fully covered in the laboratory.

Distributor Cup Assembly. The distributor cup assembly contains the two main breakers, one auxiliary breaker, the condenser assembly and the cam.

The breakers are all made of pure tungsten. They may wear out due to hammer action but will not deteriorate due to any other cause. The breakers are fitted with strong springs to give the required spring tension of 26 to 30 oz. on the main breakers. Between the breaker arms and the springs are rubber blocks the function of which is to minimize chattering. This tendency toward chattering is due to the fact that the mova-

ble contacts under the relatively great tension of the springs come down and strike the fixed breaker points a hard blow. The effect is similar to the action of a hammer on an anvil and would result in severe chatter-

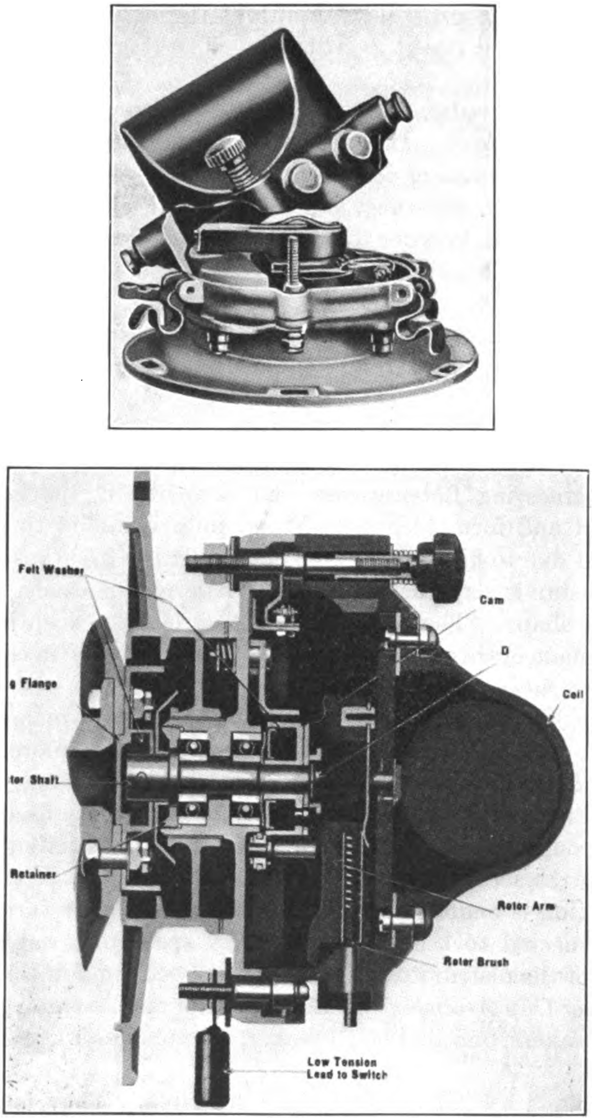

FIG. 259.—Liberty distributor head complete.

ing were it not for the rubber blocks. Chattering would not allow the primary current to build up to its proper maximum value and would result in a flux collapse of insufficient magnitude to give the required

secondary voltage. The final result would be to cause the engine to misfire. The curve in Fig. 260 illustrates, in a general way, what would occur were the breakers allowed to chatter.

Two main breakers are used for several reasons. In the first place their use increases the reliability of the ignition system. If only one breaker were used and the breaker spring should break, the points would either remain open or close irregularly. This in turn would result in the engine missing or stopping entirely. The probability of this occurring is lessened by the use of two breakers, as there is very much less likelihood of both breaker springs becoming inoperative. Should one break, the other would still function properly and give good ignition.

In the second place, should the rubber blocks not entirely eliminate chattering, the use of two main breakers would tend to minimize its effect. The two main breakers are adjusted to open simultaneously

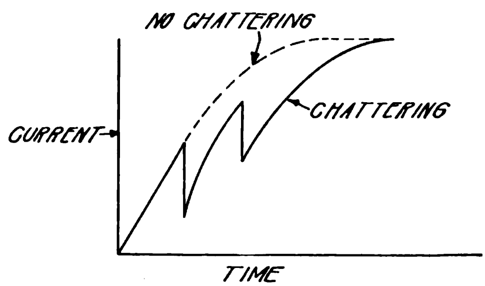

FIG. 260.—Curve showing effect of breaker chattering on building up of primary current.

within a variation of 1 degree. The adjustment will be taken up in detail in the laboratory. With both breakers opening simultaneously there is very little likelihood of their chattering in synchronism, and the primary current would build up as though there were no chattering whatsoever.

In the third place, the use of two main breakers increases the breaker life. Two breakers used together, as in the case of the Liberty system, would last considerably longer than two breakers used one at a time, as in the latter case each breaker would be forced to carry the entire primary current as against about one-half primary current in the former case.

The auxiliary breaker with its 8-ohm resistance is intended to prevent any kickback, should the engine be started with the spark lever in the advance position. There may be one kickback with this arrangement, but the engine will not fire a second time. When the direction of rotation is correct the auxiliary breaker opens 8 degrees before the main breakers and hence has no effect upon the functioning of the latter. If the direction of rotation is reversed, the auxiliary breaker will open 8 degrees after the main breakers. Thus the auxiliary breaker will be

closed at the instant that the main breakers open. The result will be that the primary current will not decrease to zero, but only to a lower value. The collapse of the flux due to this decrease in primary current is not sufficient to induce a voltage in the secondary high enough to jump the spark-plug gap under compression. Similarly, when the auxiliary breaker opens, the primary current is so small that only a very small secondary voltage is induced. Thus, in the reverse rotation of the engine, neither the opening of the main or the auxiliary breakers causes a spark in the cylinder.

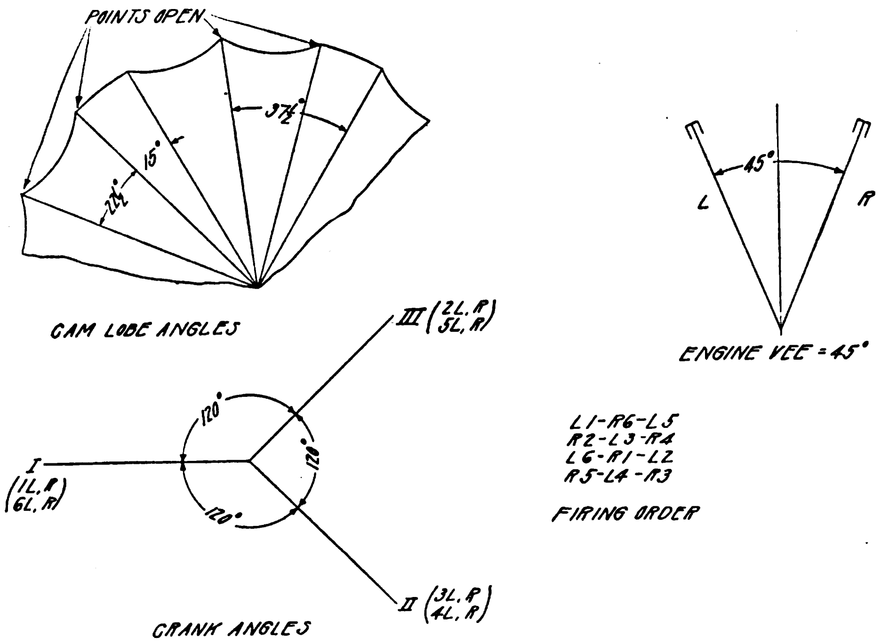

FIG. 261.—Distributor cam construction.

There are two condensers in parallel in each distributor. They are made of sheets of tinfoil separated by paraffin paper. The use of two condensers in parallel increases the reliability. Should one condenser become open-circuited, the remaining one would furnish sufficient capacity to prevent serious arcing at the breaker points, and give a good secondary spark. The latter, as in the case of a magneto, would be very weak were no condenser connected across the breaker points. This factor of reliability is only present when the nature of the breakdown in the defective condenser is an open-circuit. A short-circuit in one of the condensers would make them both inoperative.

A section of the cam, which actuates the three breaker mechanisms through the fiber rubbing blocks fastened to each, is shown in Fig. 261. The cam has 12 lobes and is driven at one-half crankshaft speed. This

illustration shows the cam lobe angles, the breaker points opening on the high points of the cam periphery. The reasons for the various angles are as follows: The engine cylinder banks are set at an angle of 45 degrees and the cranks at an angle of 120 degrees with respect to each other, as shown in Fig. 261. The crank angle diagram shows which cylinder cranks are in line.

Assume that 1*L* is the first cylinder to fire. The next one will be 6*R* whose crank has to travel 45 degrees past the point when 1*L* fired before it fires. The crank of 5*L*, the next cylinder to fire, is 120 degrees away from the crank of 1*L*, therefore it fires 120 degrees of crankshaft travel after 1*L*. As it has already traveled 45 degrees of this distance when 6*R* fires, it only has 75 degrees more to travel before it fires. The crank of

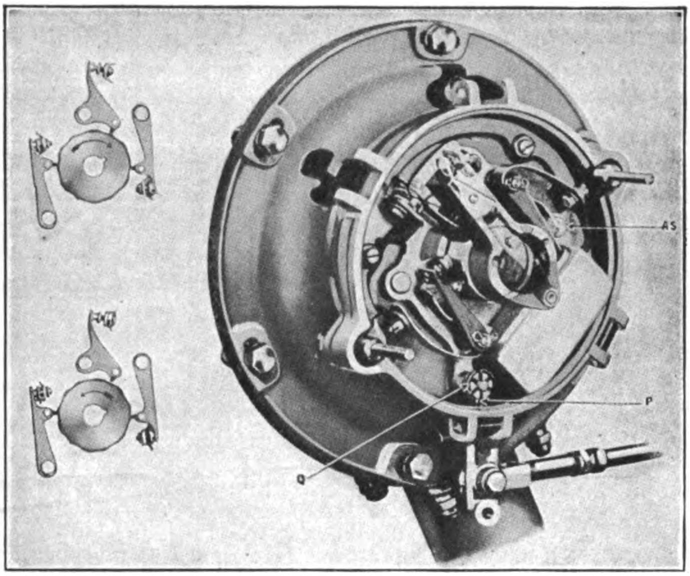

Fig. 262.—Distributor-cup assembly.

2*R*, the next cylinder to fire, is in line with the crank of 5*L* and therefore travels only 45 degrees before 2*R* fires. By further reference to Fig. 261 it will be seen that the cylinders fire at 45 and 75 degrees of crankshaft travel. Since the distributor camshaft speed is one-half crankshaft speed, the cam travels 22½ and 37½ degrees between successive sparks. This is as shown in the upper left-hand portion of Fig. 261. In order to obtain the same period of closure and therefore the same intensity of spark in each case, the points are held open 15 degrees of the 37½ degrees travel.

The distributor-cup assembly and the relative position of the main and auxiliary breakers are shown in Fig. 262.

19

Adapter Base. The distributor adapter base serves as the means for fastening the distributor assembly to the engine frame. Slotted holes in this base make possible the adjustment for synchronizing the two distributor heads. The slots allow 10 degree variation in the adjustment for simultaneous firing of two plugs.

CHAPTER VI

AIRCRAFT ENGINE DETAILS AND ACCESSORIES

Curtiss OXX-6 Engine

183. General Specifications. The Curtiss model OXX-6 engine is an 8-cylinder, V-type, 4-cycle, water-cooled engine with separate cylinders, arranged in two banks of 4 cylinders each. The angle between the banks is 90 degrees, the standard angle for an 8-cylinder engine of this type, since it is the only one which will insure even, firm impulses, and therefore the steadiest and smoothest running conditions. The method of attaching the connecting rods from a pair of opposite cylinders,

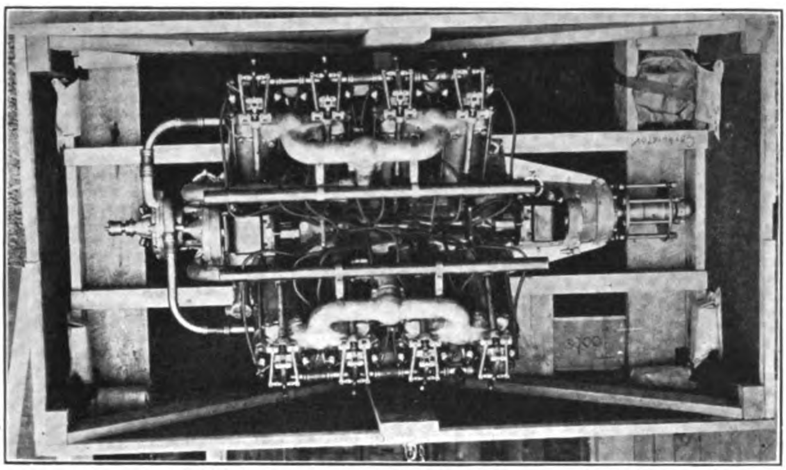

FIG. 263.—Top view of engine, showing arrangement of cylinders.

side by side in one crankpin, necessitates a staggering of corresponding cylinders on opposite banks. This gives a greater overall length to the engine and, also, a somewhat greater weight than would be necessary with an engine using forked-type connecting rods. It also increases the stresses on the crankshaft.

The OXX-6 engine is rated 100 b.hp. at 1,400 r.p.m. at sea level, the propeller being driven directly by the crankshaft. The bore is 4¼ in. and the stroke 5 in., the displacement of one cylinder being 71 cu. in., and the total displacement of the engine is 568 cu. in.

The weight of this engine, dry but with all attached accessories, is

412 lb. This gives a weight of 4.12 lb. per b.hp. and 1,278 lb. per cu. ft. of displacement. Both these figures are higher than those for the Liberty or Hispano-Suiza, due partly to the heavy materials used in the cylinder assembly and also to the bulky valve gear, made necessary by the use of overhead valves and a camshaft in the crankcase between the two banks of cylinders. The crankshaft and crankcase also are heavier in proportion to the power delivered because of the increased length necessitated by the staggered arrangement of the cylinders. An additional reason for extra crankshaft weight is in the fact that the crankpins and cheeks, because of the increased bending moment on the shaft from the use of

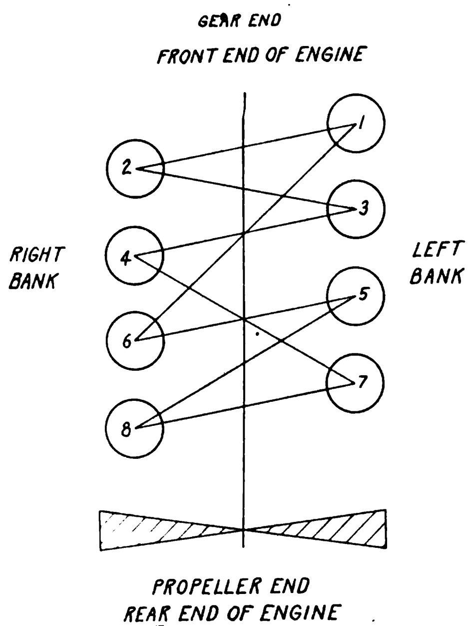

FIG. 264.—Firing diagram of Curtiss OXX-6 engine.

the sister type connecting rods, must be made heavier than would be necessary with the forked-rod construction.

The Curtiss models of the OX series had a bore of 4 in. and a stroke of 5 in., and were rated 90 hp. at 1,400 r.p.m. With attached accessories they weighed 390 lb. or 4.35 lb. per b.hp., a slightly higher figure than that of the OXX-6.

Curtiss engines of the OXX series have a bore of 4¼ in., an increase of ¼ in. over the OX models, and a stroke of 5 in. as before.

The firing order is 1, 2, 3, 4, 7, 8, 5, 6, numbering the cylinders from the gear end, with the odd numbers on the left bank and the even numbers on the right, as illustrated in Fig. 264. The direction of rotation, looking from the gear end, is clockwise.

184. Performance Figures. The maximum r.p.m. and the resultant hp. averages about 85 hp. at 1,350 r.p.m., 100 hp. at 1,400, and 104 hp. at 1,425 r.p.m.

The fuel consumption is much lower than that of the previous types, averaging about .537 lb. per b.hp., while the older types averaged between .60 lb. and .64 lb. per b.hp.-hr. These figures are for 62° (Bé.) gasoline. With the engine in good condition, the oil consumption should not exceed .026 lb. per b.hp.-hr. A consistent oil consumption figure is

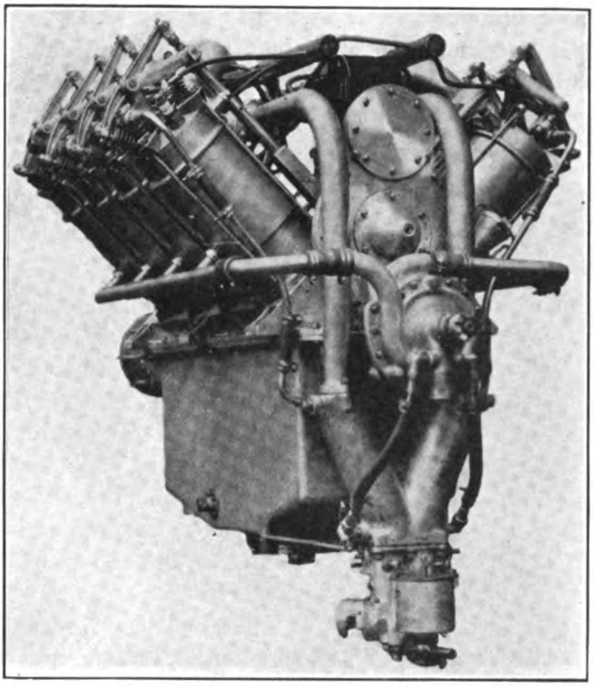

FIG. 265.—Three-fourths view of Curtiss OXX-6 engine from gear end.

difficult to obtain, as it is so greatly affected by the grade of oil used, by the condition of the engine, and by the local flying conditions.

185. Detail Specifications of Cylinders. The cylinders are cast separately of best grade gray iron, with the water jackets of monel metal, brazed on. The cylinder is machined on the outside so as to leave two ribs running circumferentially around the cylinder wall, which strengthen the cylinder and serve as bosses to which the jacket walls are brazed.

Monel metal is an alloy consisting of 68 per cent. to 70 per cent. nickel, 1½ per cent. iron, and the balance of copper. It is very tough and non-corrosive, being impervious to the action of fresh and salt water and superheated steam. This makes it ideal for water-jacket construction. The jackets, after brazing, are tested under hydraulic pressure.

The water-inlet connection is brazed to the monel-metal wall, near its base. The cast-iron head is cast integrally with the cylinder and the valves seat at an angle in the head, the valve-stem guides being integral with the cylinder casting and therefore non-replaceable. The water-outlet connection is directly in the center of the cylinder head. Two spark plugs are provided for each cylinder. They are screwed into threaded seats in the head, one on either side. The cylinder is held to the crankcase by light hold-down studs through the flange at the base of the cylinder, four of these bolts extending to a cruciform yoke over the top of the cylinder.

186. Detail Specifications of Valves and Valve Gear. The valves are of the cone-seated poppet type, the seat angle being 45 degrees. Both are one-piece valves, the exhaust of tungsten steel and the inlet of a nickel steel commonly called poppet steel. They have a lift of .461 in. and a clear diameter of $1\frac{25}{32}$ in.

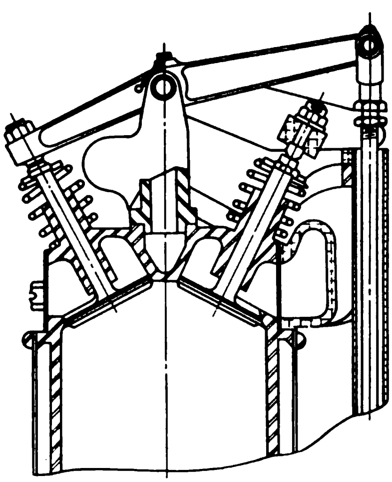

FIG. 266.—Cross-section of OXX-6 cylinder, showing water jacket, cylinder head and construction.

The exhaust springs, when compressed to $1\frac{9}{16}$ in., as they are when assembled, should have a tension of 40 to 44 lb., and the inlet springs, compressed to $1\frac{9}{16}$ in., a tension of 17 to 19 lb. The springs are retained by a horseshoe-shaped key, fitted into a groove in the valve stem, and the valves also are safety-cottered.

The valves are actuated by overhead rocker arms and intermediate push rods, one operating within the other from double-acting cams on the shaft in the *vee* of the engine. The inside rod is operated positively by the inside cam, and the hollow outside pull tube is pulled into the depression in the outside cams by a saddle spring at the base of the rod. This spring has a tension of 20 to 24 lb., which overcomes the tension of the inlet spring and opens the inlet valve. This ingenious valve-actuating device is very light in comparison with other types and is quite reliable for speeds lower than 1,500 r.p.m. It is doubtful, though, that it would serve for larger engines or for higher speeds. The cam followers, of the plunger type, are of open-hearth steel and are casehardened. Oil holes are provided for lubricating by hand the linkage in the rocker arms. The clearance between rocker arm and valve stem should be adjusted to .010 in. on both inlet and exhaust valves.

Camshaft. The camshaft is of open-hearth steel, drilled hollow, case-hardened and ground. The cams are cut integrally with the shaft. The cams and cam followers must show a scleroscope reading of 65 to 90 for acceptance. The cams are of the double-acting type, the inner cam being the positive one and the two outside cams the negative ones. The camshaft gear is of bronze, keyed to the shaft and secured with a set screw. Bronze is used with the idea in mind that this material will take all wear from the crankshaft and magneto gears, and therefore will make replacement of only the one gear necessary, rather than replacing the whole train.

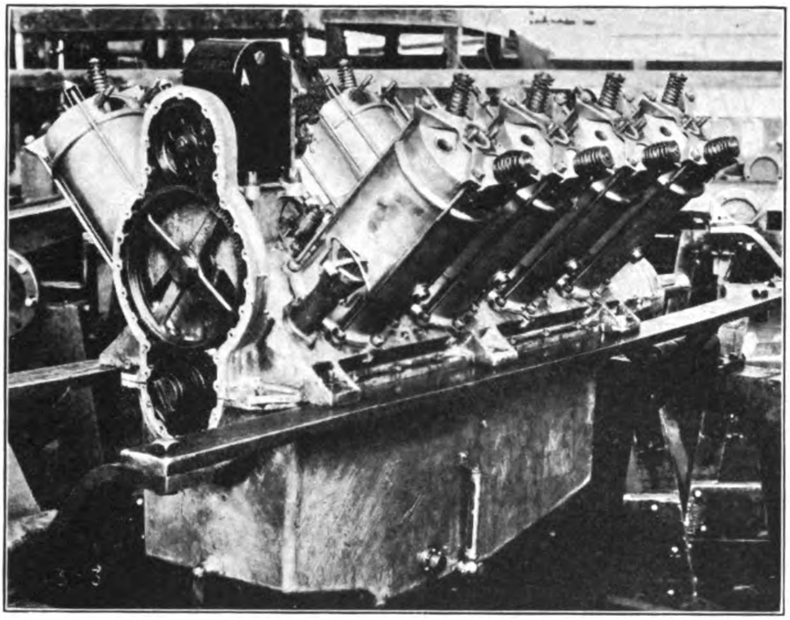

FIG. 267.—Valve gear on Curtiss OXX-6.

The camshaft bearings are aluminum alloy castings, split type, except the end bearings, which are of the barrel type. All bearings are held in place by set screws. In this engine, as in the earlier Curtiss types, the camshaft is utilized as the main oil distributing pipe and the oil is conducted from the camshaft, through leads in the crankcase webs, to the main bearings. For this reason the holes in the camshaft bearings must accurately line up with the leads in the webs. No adjustment of these bearings is possible and if worn they must be replaced.

The camshaft when assembled should have .0025 in. diametrical clearance, with a plus or minus .0005 in. tolerance, and .002 in. to .006 in. end play.

The exhaust tappet must have .015 in. play on each side, a total of

.030 in. plus the normal end play, between the outer contours of the cams.

187. Detail Specifications of Pistons and Wristpins. The pistons are aluminum alloy castings of a composition known as lynite. They are dome-shaped and made quite heavy in the head. The head is braced by two deep ribs at right angles to each other, one of which also supports the wristpin bosses.

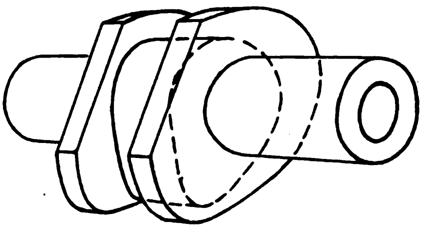

Fig. 268.—Camshaft, showing double-acting cams.

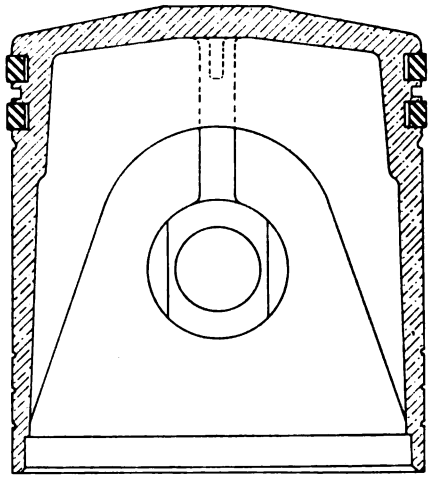

Fig. 269.—Cross-section of Curtiss OXX-6 piston.

The piston has four land diameters, diminishing toward the head to allow for the increased expansion. Numbering from the top, according to the diagram in Fig. 270, these lands should have clearance as follows:

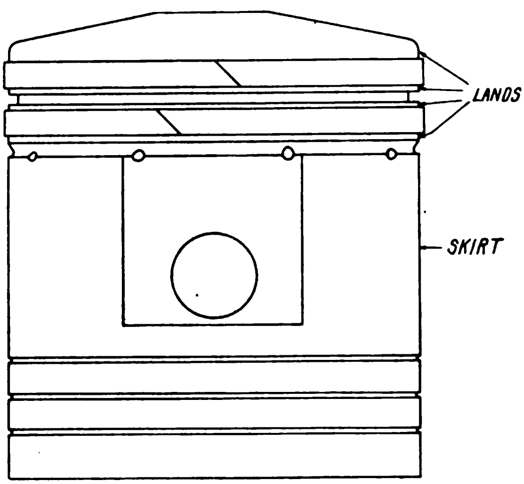

Fig. 270.—Piston clearances.

1	.019 in.
2	.013 in.
3	.010 in.
4	.008 in.

Two Burd, semi-steel rings are used in each piston. Each ring should have a gap of .015 in. to .025 in. and a clearance in its groove of .002 in. on top ring, and .0015 in. on bottom ring. The difference in groove clearance is due to the unequal expansion, the top ring being subjected to more heat. An oil groove is cut directly below the lower ring and leads are drilled through the piston wall into this groove, draining excessive oil and preventing it from working into the combustion chamber. The piston wall is relieved on the outside of the pin bosses to prevent sticking from unequal expansion and to provide sufficient oil for lubricating the wristpin bearings.

FIG. 271.—Fitting wristpin.

The wristpin is of chrome-nickel steel, heat-treated, drilled hollow, casehardened, and ground to size. The pin is retained by a set screw in the connecting rod, and has its bearing in the aluminum bosses of the piston. It should be a tight pressing fit and should require between 5 lb. and 12 lb. pressure on the free end of the connecting rod to move it in the piston. Fig. 271 shows a simple method of testing this assembly. When the parts are heated under running conditions, this will make a free-running fit.

188. Detail Specifications of Connecting Rods and Bearings. The connecting rods are of chrome-vanadium steel and carry at the big

end bronze-back bearings, held in place by brass rivets. The rods are of the H-section type and measure 8⅛ in. between centers. No definite weight is required, but in a set of eight piston-pins, rings and connecting rods, complete, no one assembly may vary from the others more than ⅛ oz. The weights of each rod and piston are checked and entered in the engine log at the factory so that in case of breakage of any part, one of the required weight may be substituted and the balance of the engine preserved. The bearing cap is held by two heat-treated chrome-steel bolts. No oil grooves are cut in the bearing surfaces but the unobstructed chamfered grooves at the edges of the bushings, which are cut to relieve the bearing metal and to collect sediment, also inevitably allow the escape of a certain amount of oil and so have the same disadvantage that diagonal grooves would have. In other engines this difficulty has been overcome to a great extent by terminating these grooves before they reach

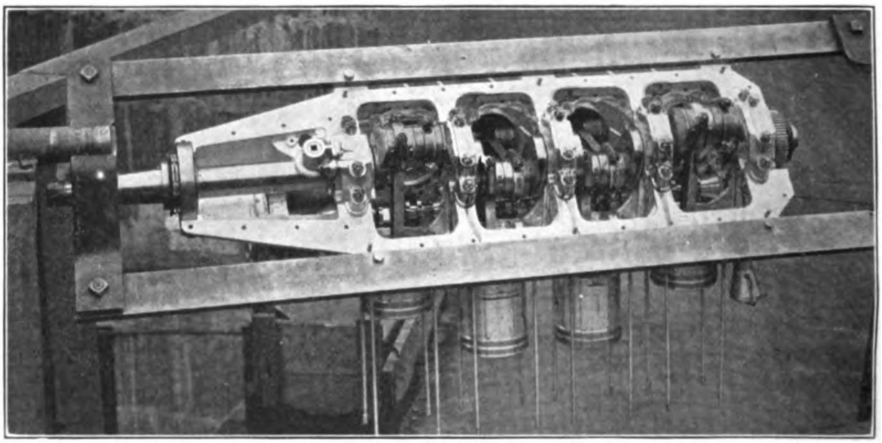

FIG. 272.—Crankcase, showing sister-rods in position.

the outer edges of the bearings. The bearings are reamed to fit a mandrel shaft .002 in. larger than the crankpin with a tolerance of plus or minus .0005 in. With both rods assembled on crankpin, there should be end play of from 1/64 in. to 3/64 in. between bearings, although no maximum or minimum limits are given.

189. Detail Specifications of Crankshaft. The crankshaft is a chrome-nickel-steel forging, rough machined, given a special heat-treatment, then finished all over and drilled hollow. It carries five main journals with overall diameters of from 1.872 in. to 1.875 in.

The crankpin journals have the same diameter limits and a length of 3 5/16 in. This extreme length is necessary because of the method of attaching the two connecting rods from corresponding cylinders in opposite banks side by side in the crankpin. This sister-rod construction has the advantage of simplicity and ease of adjustment and lubrication.

To offset these advantages there are the additional bending stresses caused by force couples and which are absent in the forked-rod construction. The oil leads in the journals are plugged by threaded caps which

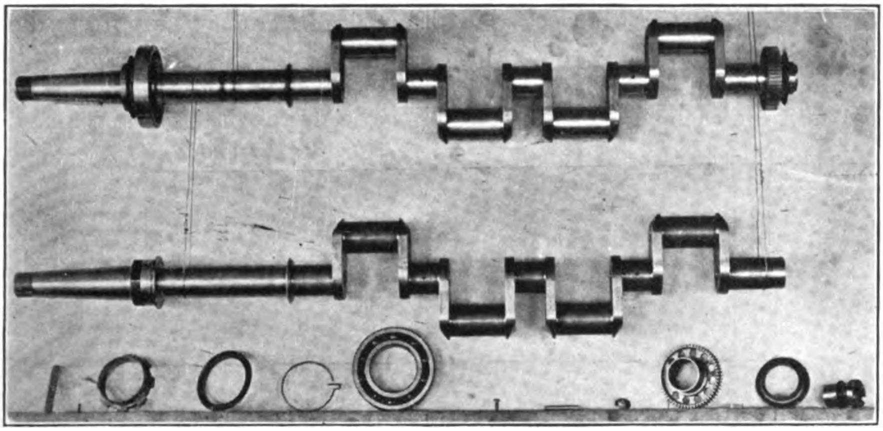

FIG. 273.—Crankshaft and thrust-bearing assembly.

are screwed into place and pierced. The main bearings should have a clearance of .002 in. to .0025 in. and a total end play of from .070 to .080 in.

A standardized propeller hub is keyed to the crankshaft. A Hess-Bright compound thrust bearing is used which, without reversing, is

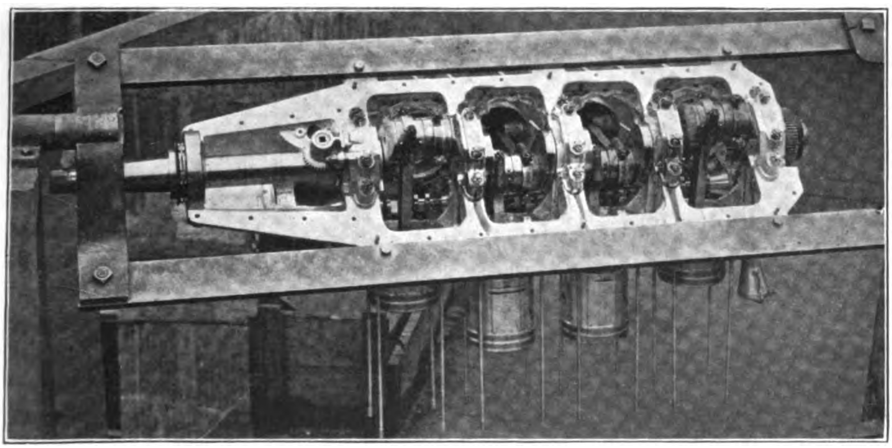

FIG. 274.—Upper half of crankcase, showing four bolts, caps, key in bearing, and also bearings fitted to mandrel.

adaptable to either tractor or pusher type engines. It differs from the simple thrust bearing used in earlier types in that it has no adjustments or adapter rings.

190. Detail Specifications of Crankcase and Main Bearings. The aluminum crankcase is of the deep-section type so that if no supply tank

is used the sump will serve as an oil reservoir. The main bearing cap supports in the Curtiss OXX-6 motor differ from the older types in that four heavy studs are used while previous types had two studs.

Bearing caps are prevented from shifting by a key, set and pinned into a groove in the crankcase web, in line with and about 1 in. from the crankshaft journal. Without this key the clearance around the studs would allow the cap to shift considerably. Two long sloping baffle plates extend from each end to the center of the sump to within ¾ in. of each

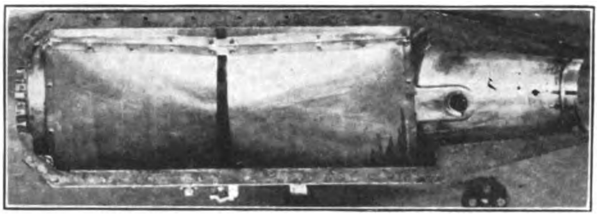

Fig. 275.—Sump showing baffle plates.

other. Besides drawing the oil to the center of the sump they also serve to prevent splashing which would flood the cylinders, particularly when flying at an angle.

Two breather tubes are provided, one at each end of the crankcase. A sight gage attached to one side of the lower crankcase section indicates the level of the oil in the sump.

A drain plug is provided which, when opened, lowers the oil level to the required height in the sump.

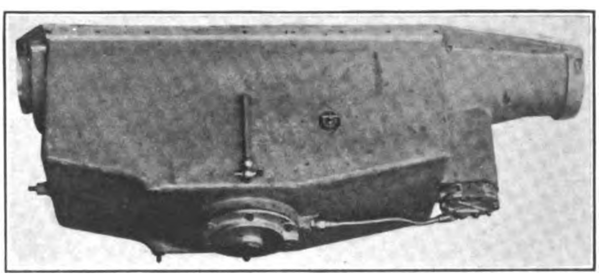

Fig. 276.—Bottom view of sump.

The main bearings are of the same type and material as the connecting rod bearings and are held in the case webs and caps by short brass screws. They are line-reamed, first roughly to .010 in. undersize and then carefully to the desired fit.

191. Detail Specifications of Camshaft-drive Gearing. A 32-tooth steel spur gear on the crankshaft drives a 64-tooth bronze gear in the camshaft, directly above the crankshaft. Since speed is inversely pro-

portional to the number of teeth, this bronze gear and the camshaft to which it is attached will travel at one-half crankshaft speed as desired.

The valve timing of the engine is as follows:

Inlet opens	10°–16° P.T.C.
Inlet closes	38°–42° P.B.C.
Exhaust opens	46°–50° B.B.C.
Exhaust closes	6°–10° P.T.C.

This is shown diagrammatically in Fig. 278.

To time the valves in reassembly proceed as follows:

(*a*) Mount camshaft without its gear.

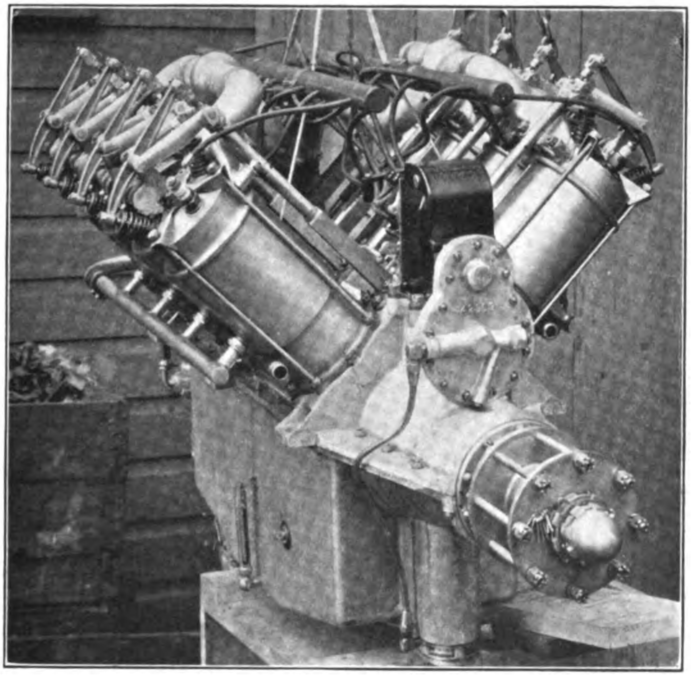

Fig. 277.—Engine showing location of drain plug, sight gage, oil connection to camshaft and pressure release valve.

(*b*) Place pistons No. 1 and No. 7 on TC.

1. Put on timing disk and pointer gage.
2. Insert plug gage in spark-plug hole.
3. Turn the crankshaft so that piston is coming up (on either side) until crank is a few degrees before TC. Mark reading on plug gage and under pointer on disk.
4. Continue in same direction until gone up and down past mark on plug gage.

5. Turn engine in opposite direction until mark on plug gage registers as in 3. Mark under pointer on timing disk.

6. Bisect subtended arc in timing disk and bring mark under pointer. Engine is on TC.

7. Set disk so that mark TC No. 1 and No. 7 is under pointer.

8. Set No. 1 on position of exhaust opening, that is, until mark EO, No. 1 in timing disk is under pointer.

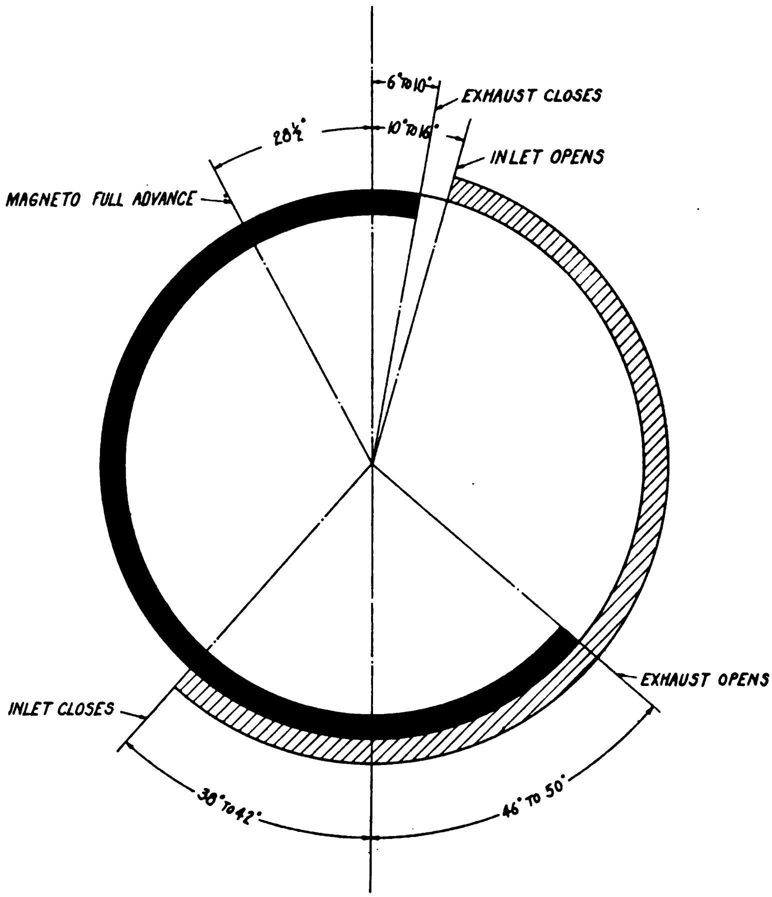

FIG. 278.—Timing diagram.

(*c*) Adjust tappet gaps to .010 in. in both valves in each cylinder.

(*d*) Turn camshaft in the direction of its rotation (counter-clockwise) until the exhaust valve on No. 1 is about to open; test with a piece of cigarette paper between tappet and valve stem.

(*e*) Place camshaft gear in shaft, meshing it with crankshaft gear, without disturbing the position of camshaft or crankshaft.

(*f*) Check timing of valve and tappet clearances. Always turn in direction of rotation to take up backlash in gears.

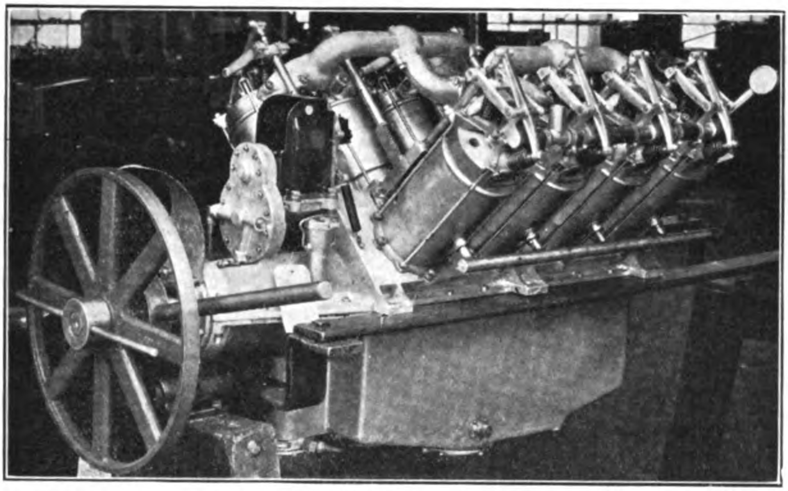

Fig. 279.—Set up for timing the valve.

In case of faulty timing it is possible to correct as follows: the camshaft gear has 64 teeth, hence a change of 1 tooth in its position on the shaft gives a change of $^{360}/_{64}$ or $5\frac{5}{8}$ degrees of camshaft travel, or since the

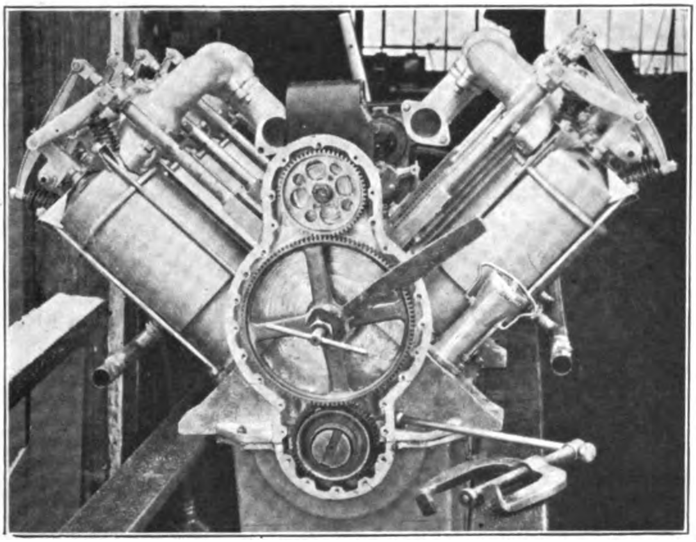

Fig. 280.—Camshaft and magneto drive gearing.

camshaft travels at crankshaft speed, $11\frac{1}{4}$ degrees of crankshaft rotations. This correction is made directly, that is, in case of late timing, the shaft

and gear are turned forward, one or more teeth as may be required. Any closer adjustment necessary must be made by varying the length of the push rods, by loosening the lock-nuts at the upper end and screwing or unscrewing the sections of the rods.

192. Detail Specifications of Attached Accessories.

Magnetos. The engine is equipped with two Dixie magnetos, Model 85, which replace the Dixie Model 81, used on previous engines, and which were also used on some of the first OXX-6 engines. This magneto is of the non-wound armature type and has a 4-wing rotor and a 4-lobe cam. The armature rotates at camshaft speed, giving four sparks per revolution or eight sparks during the complete cycle. The magnetos are carried, one at either end of the crankcase, on brackets cast integral with the upper crankcase in the vee of the engine and are driven by the half-time gears on the camshaft, one magneto rotating clockwise and the other counter-clockwise. The range of advance is about 30 degrees and the magnetos should be timed to break at full advance when piston is 28½ degrees before top center which corresponds to $^{11}/_{32}$ in. to $^{13}/_{32}$ in. of piston travel. It is advisable to time the magnetos by the use of a timing disk, as much more accuracy is possible than can be secured with a depth gage. If the engine is assembled in the plane or on the test stand and the propeller attached, it is not possible to use the timing disk and in this case the magneto advance may be checked with the depth gage, or timing rod, as it is sometimes called. At this setting, ignition on retard will occur at top center or a few degrees later. Synchronism of the breaker points is secured by adjustment of the advance levers on the tie-rod between the magnetos.

Carburetors. One Zenith Duplex carburetor, type O-6-D-S, is used. The Zenith theory and operation have been so thoroughly covered in subject "Carburetors and Carburetion" that no attempt will be made to go into details other than some of the mechanical points.

The factory setting is as follows:

Compensator	No. 115
Main jet	No. 120
Well	No. 70
Choke	No. 23

The compensator, jet and well settings are expressed in hundredths of a millimeter, and the choke in millimeters. This carburetor is fitted with an altitude valve, consisting of two small butterfly valves, one opening into each barrel just above the venturi and below the throttle valves. These butterfly valves are operated by a lever from the cockpit and, when opened, allow more air to enter above the jets, thus increasing the air proportion and also decreasing the flow of gas, due to decreasing the

pressure on the jets. The use of this altitude valve is rarely necessary below 5,000 ft.

To assist in thoroughly vaporizing the fuel, the lower part of the intake riser is water-jacketed, taking hot water from the leads over the tops of the cylinders and discharging through leads into the water pump. When properly adjusted, this carburetor should require very little care except an occasional blowing out of the jets.

Water Pump. A single pump forces the water through the cooling system. This pump is of the centrifugal type, with a cast aluminum housing and bronze impeller blades. The pump shaft is hollow and is

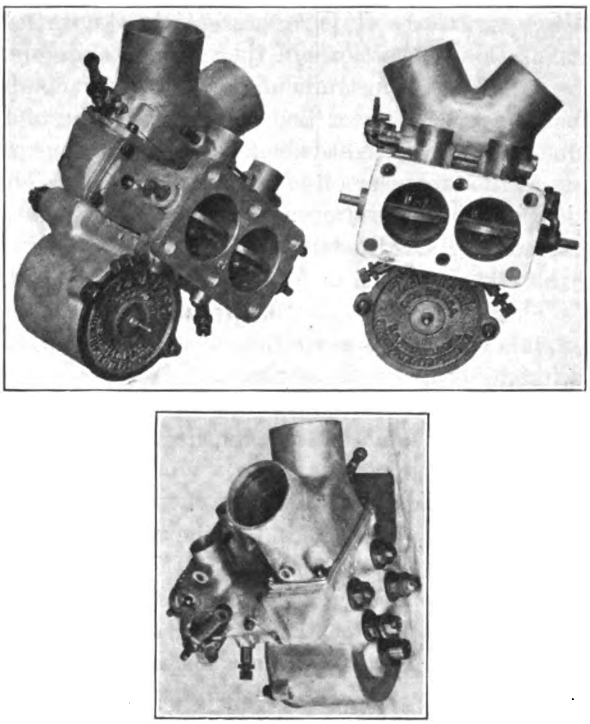

Fig. 281.—Carburetor.

driven directly from the crankshaft, to which it is connected by an Oldham coupling. The starting crank engages in a dog on the outer end of the pump shaft. At 1,400 r.p.m. the pump has a capacity of about 15 U. S. gal. per min.

Oil Pump. The oil pump is located at the bottom of the propeller end of the crankcase, and is driven by a long shaft extending through a housing in the sump and engaging in a small bevel gear driven off the crankshaft. The pump is of the gear type, consisting of one steel gear cut integral with the shaft and one gear of bronze.

193. Detail Specifications of Detached Accessories. The detached accessories in use with a given engine vary considerably with the type of machine. Some of the equipment used is as follows:

Oil Gage. The oil pressure varies with the speed of the engine and is a very important indication of the condition of running of the motor. This is measured by means of a gage working on the same principle as a steam gage; that is, a flattened tube is curved into a flat spiral and has the gage hand on the inner end. As the pressure of the oil forces into the tube, it tends to straighten out the curve and thus moves the hand in proportion to the pressure. This tube is contained in case on the instrument board and the hand travels around a calibrated scale.

Water Temperature Gage. It is very essential to know the temperature of the water, and one of the types of thermometers used is the Foxboro type with the gage on the instrument board. This type has an ether-filled tube inserted in the water line, as the reservoir of the radiator. From this tube is a long air-tight tube leading to the gage. This gage is the same type as the steam or oil gage just described. The line to the gage carries ether at high pressure, so as to be unaffected by any ordinary change in temperature. As the temperature of the water in the reservoir is increased, the ether expands in the first tube or the part screwed into the radiator. This increases the pressure in the line which works the gage in the same manner as any pressure gage. The dial, of course, has to be calibrated for the proper temperatures.

Oil Temperature Gage. The temperature of the oil is registered on the instrument board in the same manner as the water temperature. The gage used is the same type and make.

Tachometer. There are various types of tachometers used to give the instantaneous speed of the engine. The type most used with the OXX-6 engine is the Reliance Tachometer. This type works on the principle of the governor. A flexible shaft leads from the end of the camshaft to the case of the tachometer which is located on the instrument board. This shaft registers the speed of the camshaft or half the crankshaft speed. The upper end of the flexible shaft is connected to a cross shaft in the instrument case. This latter shaft has a light three-weight governor, running on ball bearings and rotating with the shaft. As the speed increases the weights are thrown out from the axis, due to the centrifugal force, and move a sleeve along the small shaft. This sleeve has an attachment to the hand on the indicator dial and moves the hand in proportion to the increase in speed. The dial is calibrated to read directly the speed of the crankshaft, in revolutions per minute. The indicator has a scale reading from 200 to 2,400 r.p.m.

194. Detail Specifications of Fuel Supply System. The fuel system, as used with the OXX-6 engine, must depend entirely upon the type of machine or work to which the engine is to be applied. This motor was,

however, used by the Navy, mostly in the N-9 type machines which were equipped for about two hours flight.

Two hours flight with the OXX-6 motor would require about 20 gal. of gasoline, figuring on a consumption of .661 lb. per hp.-hr. This is the case in the standard N-9 machine. There is a 20-gal. gasoline tank slung in a cradle just back of the engine and ahead of the observer. This tank is protected from the heat of the engine and backfires by a metal firewall extending completely across the fuselage between engine and tank. This tank is raised so the curved top surface is at the same height as the cowl on the forward section of the fuselage. The position of the tank gives the gasoline a good head so that it is not necessary to use pressure. The system is therefore a gravity feed and requires no pumping arrangement nor a pressure gage. A gasoline gage is attached to the tank, the face of which extends above the cowl surface so the pilot or observer may determine the amount of fuel on hand at any time. This gage is plainly visible from both pilot's and observer's cockpits.

From the tank, a single supply line leads through the firewall to the carburetor bowl. This line is of copper or some metal not affected by gasoline or very easily crystallized by vibration. There are also expansion coils in this line to prevent vibration or sudden jars from breaking the feed line and possibly causing a fire.

The carburetor, as previously explained, is a duplex type, having two air intakes and two mixing chambers. It has, however, only one float chamber and one gasoline intake line.

In the feed line to the carburetor is placed the gasoline valve and also a trap for catching any water that might be in the fuel. The controlling handles for the valve are placed on the dash or instrument board in the pilot's and observer's cockpits. These handles are connected to the shaft operating the valve by a universal joint.

195. Detail Specifications of Cooling System. The cooling water is forced through the system by means of a single centrifugal pump. This pump has been described previously.

The circulation is from the pump, through a Y-pipe to the lower outside of the cylinder banks. Part of the water goes to each side of the Y and from there to the distributing pipe, running along the lower outside of the cylinders. From this distributing pipe there is a branch pipe to each cylinder water jacket. The branch pipe leads the water in at right angles to the cylinder wall, and the water after heating rises to the top of the jacket to the outlet pipe. The outlet pipe of each cylinder is integral with the rocker-arm support and is located at the top center of the cylinder.

The outlet pipes are all connected by short lengths of rubber tubing between each pair of cylinders. The outlets of cylinders No. 7 and No. 8 are connected to the radiator. The outlets of No. 1 and No. 2 are closed

except for a small bypass which conducts hot water around the intake manifold.

From the lower end of the radiator a single pipe returns the water to the pump, thus completing the system.

The water temperature should be allowed to run between 150° and 160° F., although in very warm weather this temperature may rise to 180° F.

196. Detailed Specifications of Lubricating System. The proper lubrication of any mechanism is of so vital importance, and any neglect is so sure to cause expensive repairs, that the mechanician should make it his unfailing habit to look after it daily. The Curtiss lubrication system is easily understood and requires little time for proper attention. The system is force-feed and spray. The sump is used as the oil reservoir and carries a sight gage that indicates at all times the quantity of oil it contains. The sump is so designed that its center is always its lowest point and is consequently the point at which the oil gathers. This is a highly important feature, as at no practical flying angle can the cylinders become flooded with oil.

A single-gear pump, which has been described, draws the oil from the low point of the sump through a pipe connection and forces it through another pipe connection into the hollow camshaft and to the camshaft bearings; thence through connecting leads in the crankcase webs to the crankshaft bearings. From these bearings the oil passes through the holes drilled in the crankshaft into the hollow crankshaft and hollow throws to the connecting-rod bearings. The oil is thrown off the crankpin bearings in a spray to the piston-pin bosses and through holes in the bosses to the piston-pin bearings. The spray from the crankpin is also thrown on the lower part of the cylinder walls and is carried by the piston to the upper part of the walls. The magneto gear and camshaft gear are lubricated by spray from a hole in the retaining screw of the camshaft gear. The thrust bearing is lubricated by spray from the crankshaft.

All bearing pins for the rocker arms and for the forked ends of the push rods are hollow, but plugged at both ends. Minute holes are drilled in alignment with the external holes. As oil is forced into these external holes the hollow spaces inside the pins act as reservoirs and will oil evenly all bearings of the rocker-arm mechanism for several hours after being filled.

The oil pressure is controlled by a small ball and spring regulator-valve placed in the oil line and acting as a bypass, allowing the surplus oil to flow into the sump. This valve is placed at the junction of the camshaft and the oil line from the sump and the valve housing is an integral part of the camshaft gear cover plate. Fig. 274 shows clearly

the location of the regulator valve and of the drain or bypass into the sump.

The maximum oil pressure may be adjusted by changing the thickness of the fiber washer under the head of the retaining screw which bears against the spring, this increasing or decreasing the pressure at which the valve will open. The spring may be removed by taking out the cap screw which encloses the valve and retains the spring. The oil pressure at 1,400 r.p.m. should be between 55 lb. and 80 lb. The pressure gage is attached to the two-way cock which connects the oil line to the camshaft gear cover plate. The oil temperature should be maintained

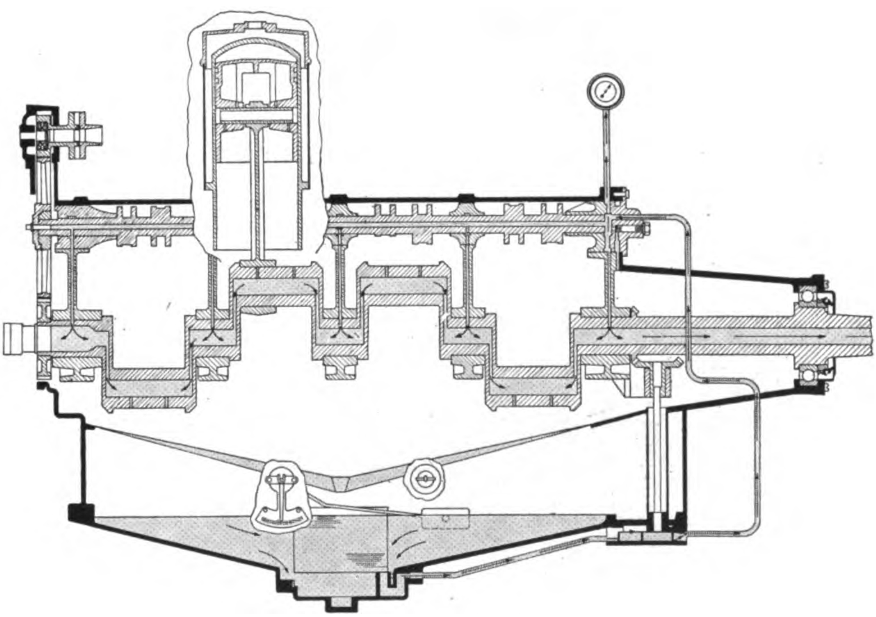

FIG. 282.—Lubrication chart of Curtiss OXX-6 engine.

between 110° F and 130° F. A higher temperature than this is a symptom of trouble.

Hispano-Suiza Engine, Model A

197. General Specifications. The model "A" Hispano-Suiza Aeronautical engine is an 8-cylinder, V-type, 4-cycle, water-cooled engine. The banks are cast in blocks of 4 cylinders each, with the banks set at 90 degrees to each other. Corresponding cylinders in each bank are directly opposite. The 90-degree V-type engine insures an even firing sequence, giving steadier running conditions than would be obtained from any other 8-cylinder arrangement. This is of increased importance as the number of cylinders decreases. The method of re-

taining the separate sleeves in the water-jacket castings gives a simple and strong construction, but does not aid cooling to any extent.

The engine is rated at 150 hp. at 1,450 r.p.m. at sea level.

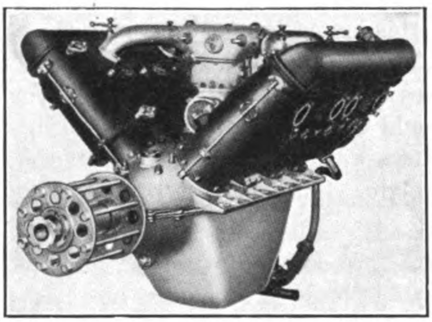

Fig. 283.—Three-quarter front view of model A.

The cylinder bore is 120 mm. (4.724 in.) and the stroke 130 mm. (5.118 in.). This is known as a low-compression engine, the compression-volume ratio being only 4.72 to 1. Model "E," of the same engine, having the same bore and stroke, develops more power by using a higher

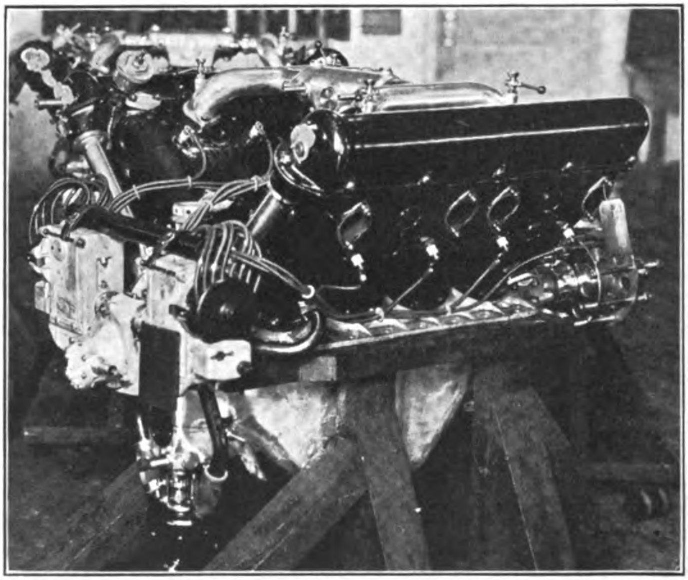

Fig. 284.—Three-quarter rear view of model A.

compression and higher speed; the former is obtained by setting the wrist-pin lower in the piston skirt, thus decreasing the clearance volume.

(*a*) The weight of the engine complete with attached accessories is 445 lb.

(*b*) The weight per rated hp. is 2.96 lb.

(*c*) The weight per cu. ft. displacement is 1,070 lb.

The values in *b* and *c* are both rather high due to the heavy water-jacket castings which weigh approximately 47 lb. each. If these were replaced by light sheet metal jackets with a separate camshaft housing, as on the Liberty, the weights would be greatly reduced. This is a good example of the influence of design upon performance. In the model E of this engine, with the same weight and dimensions, we get increased total power as shown above, and hence lower weight per hp. and per cu. ft. displacement.

The cylinders are numbered in right and left banks from the propeller end, just the reverse of American practice, although the banks are named

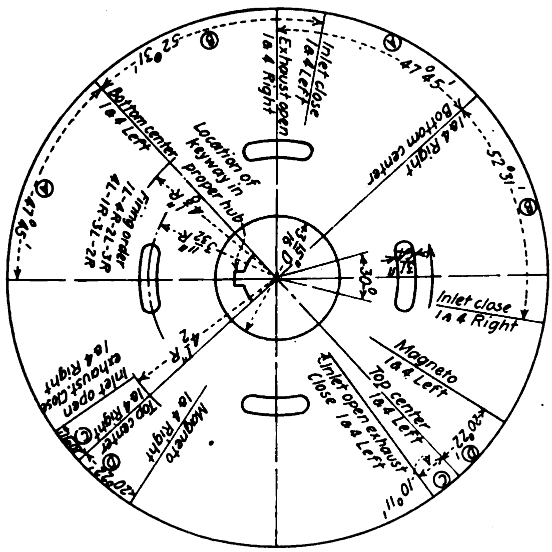

FIG. 285.—Timing diagram, models A, I and E.

looking from the gear end. The firing order on this basis is: 1L, 4R, 2L, 3R, 4L, 1R, 3L, 2R. See firing-order diagram in Fig. 285. It will be noticed that this arrangement gives a combined firing order of 1st, 2d, 4th, 3d cylinders in each bank, looking from the gear end in the right bank, and from the propeller end in the left. This gives a good distribution of stress and insures even, quiet running. Looking from the gear end, the engine runs in a clockwise direction.

198. Performance Figures. The following data prove that in practice these engines develop very close to their rated output:

Hp. output	at	R.p.m.	Where tested
154		1,500	U. S. Navy Gas. Eng. School.
147		1,440	Wright-Martin Factory.

In the factory acceptance test every engine must develop at least 140 hp. at 1,450 r.p.m.

The rate of fuel consumption is usually low, varying from .526 lb. per hp.-hr. to .55 lb. per hp.-hr. An average rate of .54 lb. per hp.-hr. may reasonably be expected.

Although the engine shows a tendency to run hot at low altitudes the oil consumption is normal, varying from .0178 lb. per hp.-hr. to .0388 lb. per hp.-hr., averaging about .03 lb. per hp.-hr.

199. Detail Specifications of Cylinders. The cylinders are of the valve-in-head, assembled type; valve cages, gas and water manifolds, and water-jackets being included in an integral block casting into which the separate barrels are screwed.

These barrels are of 40-carbon steel, machined inside and out, from drop forgings. The block water-jacket castings are of aluminum alloy,

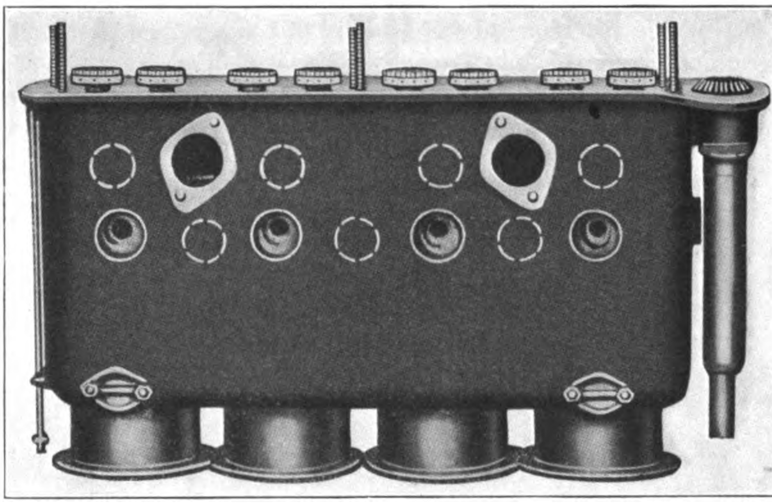

FIG. 286.—Cylinder and sleeve assembly, models A, I and E.

90 per cent. aluminum and 10 per cent. copper. This combination gives a strong durable working barrel with superior wearing qualities, and a comparatively light, highly conductive material for the water-jackets. The barrels are threaded from the heads to within $2\frac{3}{8}$ in. of the hold-down flanges at the bottom, and screw into wells in the jacket casting which are tapped out to receive them. A hold-down flange is machined at the base of each barrel, providing a means of attachment of the whole assembly to the crankcase. The cylinder heads are flat and the walls of the combustion chamber are not flared as in the Liberty cylinders.

The height of the cylinders, from crankcase deck to top of water-jackets, taken along the center line, is $14\frac{3}{16}$ in.; the projected or effective perpendicular height above the highest point of the deck is $10\frac{1}{2}$ in.,

giving a "height ratio" of .74 for this 90-degree angle, as compared to .92 for the 45-degree angle on the Liberty, and .70 for the 90-degree angle on the Curtiss OXX-6. Similarly, the effective horizontal distance from the vertical center plane of the crankcase to the outermost point of the water-jacket is 15 in., while the distance from the same plane to the extremity of the supporting flange is 7$\frac{9}{32}$ in., which is a fixed minimum width figure of engine for any arrangement of cylinders. Combining these dimensions we get a "width ratio" of 2.05 for this 90-degree angle, in comparison with 1.26 for the Liberty with its 45-degree angle, and 1.73 for the Curtiss OXX-6 with its 90-degree. The "ratio of ratios" or "area ratio" in the three cases under discussion will then be: 1.52 for the Hispano, 1.15 for the Liberty and 1.2 for the Curtiss. Considering the Liberty ratio as unity we will have: 1.3 for the Hispano, 1.0 for the Liberty and 1.04 for the Curtiss, which gives us a comparison of the head resistance offered by the different angular arrangements, assuming that the space between the banks offers as much resistance as the banks themselves, and, when we consider that this space is filled more or less completely by the inlet manifolds, carburetors or magnetos, we may for the purpose of making this rough comparison assume that it is solid.

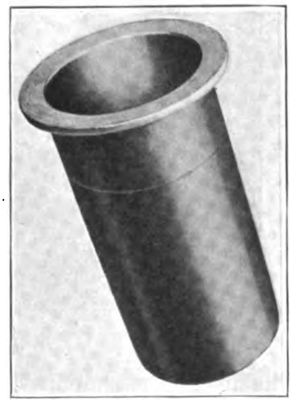

Fig. 287.—Cylinder liner (threaded), models A, I and E.

The width of the jacket casting is 6$\frac{13}{16}$ in. and the average weight of barrel and water-jacket assembly per cylinder is 17 lb.

The valve seats are in the barrel head and are of the beveled type, the cone angle being the conventional 45-degree angle.

The valve cages are integral with the jacket casting, being cored in the mold. This is a simple construction, the only disadvantage being in the fact that a press fit forms the connection between the valve seat in the barrel head and the cage in jacket casting. Any failure of this metal-to-metal fit will interpose an air gap in the heat path and seriously interfere with proper heat transfer, causing warping of the head and seats.

The stem guides are of cast iron and machined all over. They are threaded on the outside to screw into the seats in the top of the valve cages which are tapped out to receive them.

The valve-port flanges are of aluminum, fused to the main casting and carrying two studs for the attachment of the manifold flanges.

The spark-plug seats are steel bushings threaded to screw into tapped holes in the cylinder-jacket walls. The inner end extends through a corresponding hole in the barrel wall and the bushing seats against the

jacket wall proper, on the outside. Both this joint and the inner one, which is protected by a bronze bushing, must be tight. Two spark plugs are used per cylinder, placed at opposite ends of a transverse diameter, the centers of the bushings being ⅞ in. below the cylinder head.

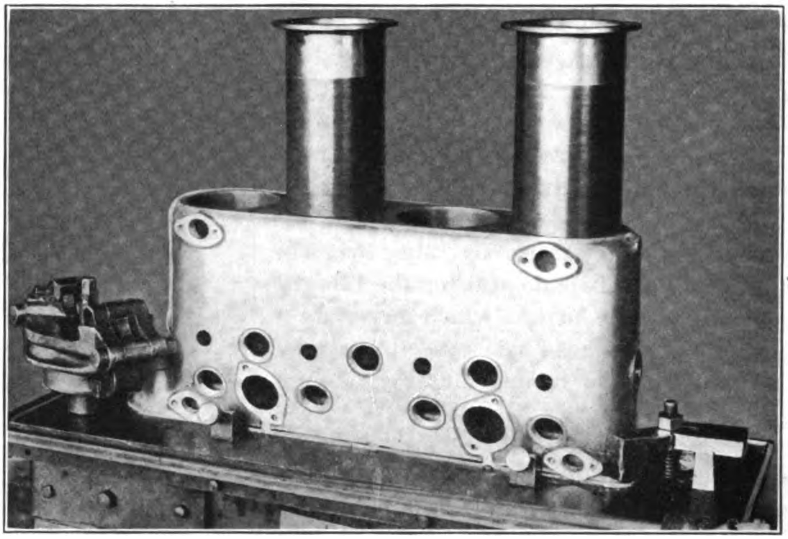

FIG. 288.—Section of sleeve and jacket assembly, models A, I and E.

The use of two spark plugs insures the ignition of the charge simultaneously at each side of the combustion chamber, and while the points theoretically should be in the cylinder heads, this arrangement serves all practical purposes.

The cylinder assembly is attached to the crankcase by means of studs through hold-down flanges at the base of the several cylinders, eight ¼ in. studs with plain hexagonal nuts being used per cylinder. Owing to the close spacing of the barrels in the block it is necessary to cut away the sides of the hold-down flanges on two alternate cylinders, and these two must be fitted first.

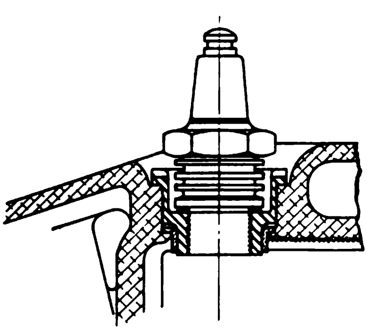

FIG. 289.—Spark plug seat details, models A, I and E.

It will be noticed that the two studs on each cylinder come very close to the corresponding studs on the adjacent cylinder, giving just enough room to turn up the nuts with a special wrench. On the later models these pairs of studs on adjacent cylinders have been replaced by one, and the holes changed to slots, a heavy washer being used to hold the two separate flanges together as on the Liberty.

The process of manufacture of the cylinder barrel is as follows: The rough forgings, after undergoing a rigid factory and government inspection, are machined inside and out; ground inside, first rough by the wet process and finished by the dry process; then the threads on the outside cut in a turret lathe, five tools being carried in one holder and all cuts, rough and finish, taken in one operation. The set-up for this last operation must be most carefully made, as a high degree of accuracy is required in the thread cutting in order to give the maximum amount of bearing surface, and hence, the best possible heat path from barrel wall to jacket wall. The hold-down flange is finished, and the stud holes drilled by a gang drill. The barrels are put through a heat treatment after which the flanges are again trued up.

The process of manufacture of the water-jacket is as follows: The metal is poured into a mold carried in four flasks, chills being used to cool the thicker parts of the metal uniformly with the thinner ones. The casting is chipped, ground, thoroughly cleaned of sand by rotating between off-set centers while partially filled with "jack-straws," and

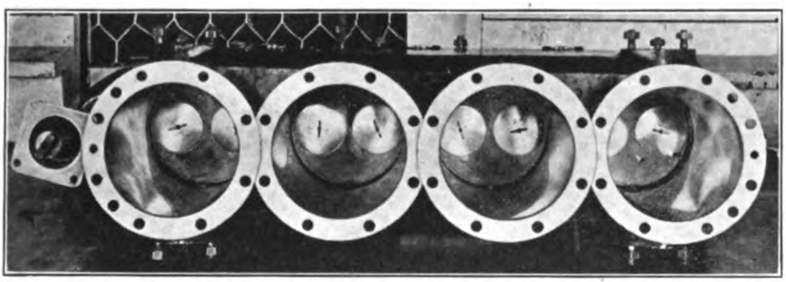

FIG. 290.—Bottom view of bank, models A, I and E.

tested for leaks under hydraulic pressure. Port flanges are fused on. Core-print holes and seats for the stem guides and spark plugs are tapped. The barrel wells are also tapped out, this operation being most carefully done, as noted above in the case of the cylinder barrel threading.

The barrels are screwed into the wells and the tops of the heads tested for contact with the jacket casting with prussian blue—80 per cent. bearing surface required. When all barrels are fitted the bottom surfaces of the hold-down flanges are planed off even, and the valve and spark-plug openings are drilled in the barrels to coincide with those in the jackets. Both operations are performed on gang drills, all holes of one kind being drilled at the same time. Individual barrels are replaceable, but from the above it will be seen that the operation is a factory one, and cannot be performed with the usual base-shop equipment. The outside of the jacket casting and the inside of all water and gas passages, as well as the outside of the barrels below the jacket, are enameled and

the several coats baked on. The valve seats are reamed and the stem guides inserted.

200. Detail Specifications of Valve and Valve Gear. The valves are of the cone-seated poppet type and are carried vertically in the cylinder head, along the center line of each block, and not transversely as in the Curtiss and Liberty. This arrangement is made possible by the fact that no rocker arms are used, the valves being actuated directly by the cam faces. The lift is 10 mm. (.393 in.) and the clear diameter 50 mm. (1.968 in.). The outside diameter of the head is approximately 2⅛ in.

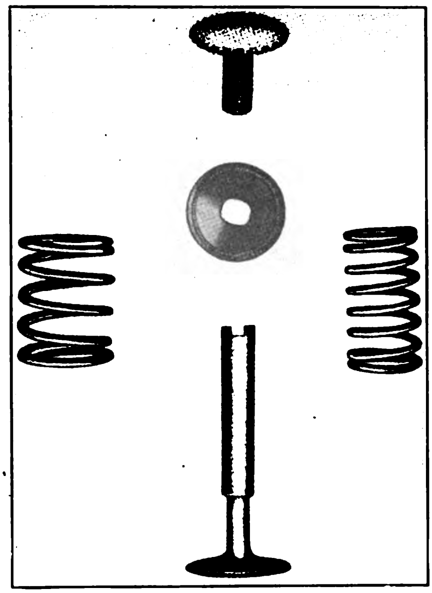

Fig. 291.—Valve assembly, model A.

The heads are of tungsten steel welded to a carbon steel stem ⅜ in. in diameter for the first inch above the head, then increasing to ⅝ in., this upper portion being hollow and tapped out to receive the threaded stem of a casehardened head, or anvil, upon which the cam face bears. Washers with serrated rings on the upper surface ride on top of the springs and bear against the under side of this anvil, which also carries a serrated ring meshing with that on the washer, locking the anvil. The washers are held in position on the stem by means of flattened sides on the latter. This construction provides a very accurate method of adjusting tappet clearances and securing them against change.

The stem guides are reamed to the following clearances:

TABLE XXI.—CLEARANCES OF STEM GUIDES

Valve	Min., in.	Max., in.	Desired, in.
Inlet—top	0.0023	0.0043	0.0033 (loose)
Inlet—bottom	0.0038	0.0058	0.0048 (loose)
Exhaust—top	0.0023	0.0043	0.0033 (loose)
Exhaust—bottom	0.0043	0.0063	0.0053 (loose)

Springs are used per valve, of the following specifications:

TABLE XXII.—SPECIFICATION OF SPRINGS

Spring	Number of effective coils	Gage of wire	Direction of helix	Strength at
Inside—both	7	8	Right	To be
Outside—exhaust	5	6	Left	deter-
Outside—inlet	5	6	Left	mined

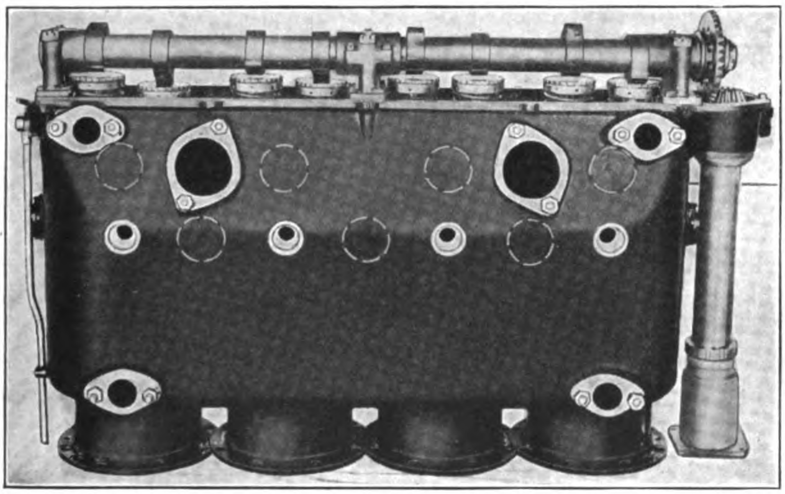

FIG. 292.—Camshaft models A, I and E.

The springs seat on collars on the valve stem guide bushings, and are held at the top by the washers described above.

Rocker arms are not used on this engine but the cams act directly on the valve anvils.

The camshaft is of tubular section, somewhat heavier than that on the Liberty, since it is carried in only three bearings. The cams are forged integral and are drilled on the back side for oil holes. The shaft is of nickel-chrome steel and is drilled radially at each journal to provide

for the lubrication of the bearing surfaces, and the gear end is provided with two large, and four small holes, to carry off the excess oil. One or more of these holes may be plugged in order to restrict the oil flow in the shaft and so force out more to the bearings, cam faces and valves. The drive gear, of nickel-chrome steel casehardened, is attached to the gear end of the shaft and held by a woodruff key fitting in any one of five equally spaced keyways in the gear hub, and by a castellated nut which turns up on the shaft and is locked by a cotter pin. It will be

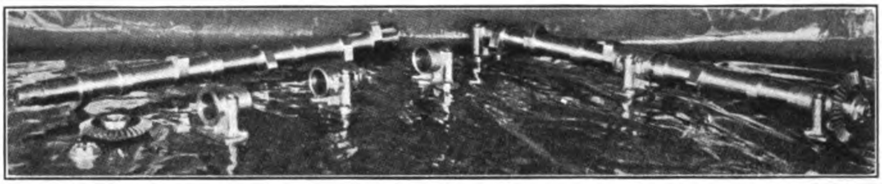

Fig. 293.—Details of camshaft bearing.

noticed that this gear is *behind* the vertical driveshaft pinion, thus giving a reversal of the direction of camshaft rotation, compared to that of crankshaft rotation. The gear has 36 teeth, hence there are 7⅕ teeth in the subtended arc between two keyways, and a change of one keyway in gear position gives a change of ⅕ tooth in the valve timing.

The camshaft housing consists of the upper part of the cylinder-jacket casting carrying the valve gear, and a removable cover plate, also of aluminum alloy. The joint between them is provided with a gasket in order to make it oil tight. The shaft is carried in three bearings

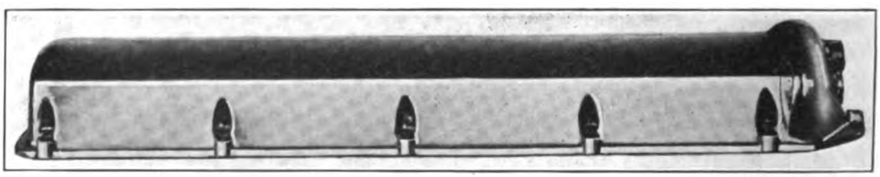

Fig. 294.—Cut of camshaft cover.

held to the cylinder-jacket casting, four studs to each bearing seating in the casting. The bearing at the gear end, carried between the first exhaust cam and the drive gear, takes the thrust. The propeller-end bearing is drilled to carry oil from the external oil lead, from the crankcase to the bearing surface.

It will be noticed that with this bearing design it is impossible to draw out the camshaft horizontally without loosening all the bearing caps, as the drive pinion is in front of the camshaft gear. In any event the end play in the thrust bearing is too small to allow such a movement of the shaft, and in order to raise it out of this bearing, it is necessary to loosen all caps.

The clearances and tolerances are as follows:

TABLE XXIII.—CLEARANCES AND TOLERANCES

Camshaft	Min., in.	Max., in.	Desired, in.
Diametrical clearance	0.002	0.004	0.003 (loose)
End clearance—between front bearing and gear	0.010	0.030	0.020 (loose)
End clearance—between rear exhaust cam and bearing	0.010		
Clearance between back of cam and anvil	.....	....	0.079

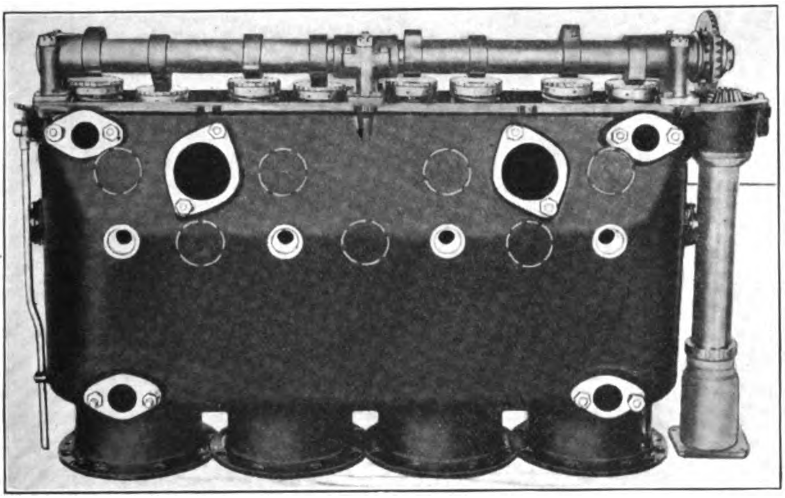

FIG. 295.—View of one bank with camshaft in position, models A, I and E.

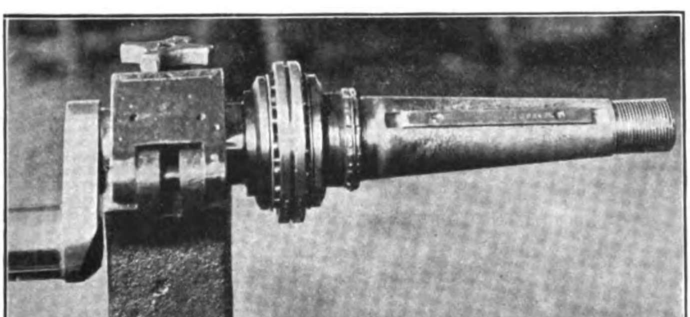

FIG. 296.—Propeller end camshaft bearing and oil leads, models A, I and E.

The steel disk, which plugs the open end of the propeller end bearing is spun, or peined, into place—fit .004 in. (tight or loose).

These bearings should be line-reamed, and care taken to see that

the oil passages in the cylinder-jacket casting, bearing piece and shaft at the propeller end, all line up.

The tachometer drive is taken off the gear end of the camshaft, a tooth in the former locking in a slot in the shaft, and not in one of the oil-escape holes.

201. Detail Specifications of Pistons and Wristpins. The pistons are of the thin-head type with cooling ribs running at right angles to the wristpin. The wristpin bosses are relied upon to give the extra metal necessary for proper heat conduction on the sides not reached by the ribs. This type of piston is not satisfactory and has been replaced on the later models by the solid-head type as used on the Liberty.

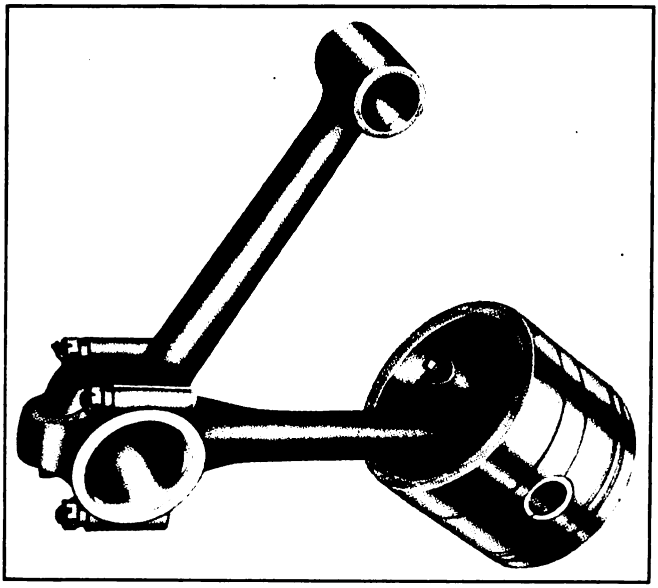

FIG. 297.—Piston, showing ribbing and wristpin retaining screw, model A.

The piston, without rings or wristpin, weighs from 1.6 lb. to 1.8 lb., but all pistons on one engine must not vary more than $\frac{1}{4}$ oz. Head diameter 4.69 in., skirt diameter 4.71 in., height $3\frac{15}{16}$ in.

Each piston is provided with five rings, four being compression rings carried in two grooves, and one an oil ring with a beveled edge, carried in a groove at the lower end of the skirt. The compression rings have plain 45-degree gaps; which are turned in opposite directions in each pair, in one groove. The oil ring has a "wiping" effect on the sharp edge, which may be utilized in sweeping oil up or down on the cylinder wall as the need may be. All rings are concentric.

One oil groove is provided on each piston, extending half-way around the skirt at the height of the center-line of the wristpin bosses, and form-

ing a connection between them, thus providing an oil lead from piston wall to wristpin bearing. In assembling the piston on the connecting rods, this ring should face inward, toward the *V* of the engine.

The wristpin bosses are carried about half-way down the piston skirt, or $1\frac{49}{64}$ in. below the head, this position giving the minimum "slapping" effect. The center of the bosses is $1\frac{13}{16}$ in. below the piston head. The skirt is not as heavily relieved around the bosses as in the Liberty pistons, merely a thin layer being taken off in this case.

The wristpin is of tubular section and is not full floating, but is held from rotating in the piston bosses. It is held securely in the piston by a single set screw in one boss, which passes completely through one end

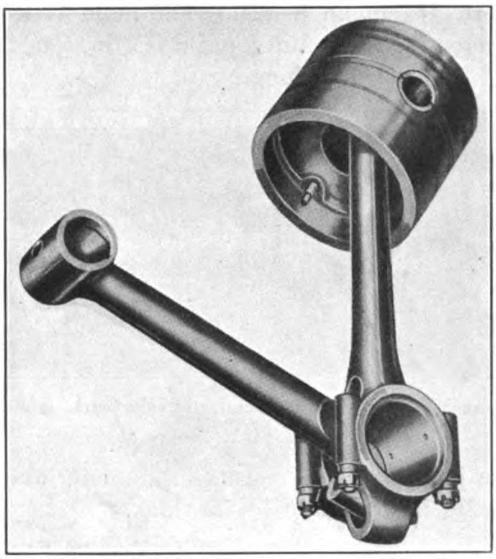

FIG. 298.—Piston and connecting-rod assembly, model A.

of the pin. The wristpin is of alloy steel casehardened. This is not as satisfactory as a full floating pin, although it simplifies the method of retention, and has given way in the later models to the full floating type.

202. Detail Specifications of Connecting Rods and Bearings. Connecting rods are of tubular section and of the forked-and-plain type. This section gives a heavier rod for the required strength, but in view of the short length, this is not a serious objection. It has the advantage of affording a slightly better heat path at the big end, through presence of more metal at the junction between rod and bearing cap. The material is alloy steel, heat treated.

The plain rod, with bearing bushing, weighs $2\frac{3}{8}$ lb., the forked rod alone, with forked cap, $2\frac{5}{8}$ lb. The length between centers is $8\frac{7}{8}$ in.

Both bearings are of babbitt carried on the inner and outer surface of a steel shell, held in the plain rod.

This support at the center of the shell is not as secure as the Liberty method, where the bushings carried by the forked rod are held at each end, and hence is not so easy to keep in alignment. The later models use a modification of the Liberty design. The legs on the forked rod are held against spreading by a bridge across the two legs of the cap portion. This is a good feature and a stronger construction than that on the Liberty.

203. Detail Specifications of Crankshaft. The crankshaft is of the four-throw type, 180 degrees between throws, and is of tubular section of nickel-chrome steel. The shaft complete, with thrust bearing, weighs 55 lb. and is 3 ft. $4\frac{1}{4}$ in. in length. The main bearing journals are $2\frac{9}{32}$ in. in diameter. No. 1 main journal is 1 in. long; Nos. 2, 3 and 4, $1\frac{5}{8}$ in. long, and No. 5, $3\frac{3}{4}$ in. long.

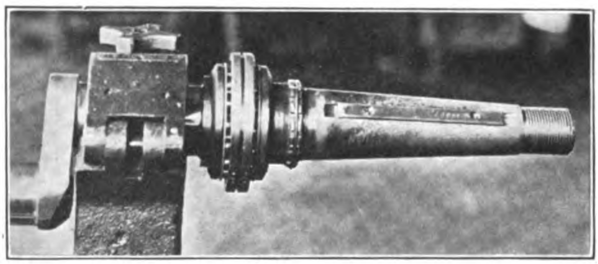

FIG. 299.—Crankshaft with thrust bearing propeller curb, models A, I and E.

The crankpin journals are $1\frac{63}{64}$ in. in diameter and $2\frac{17}{32}$ in. long, the crankcheeks $2\frac{3}{4}$ in. wide and $1\frac{7}{8}$ in thick.

The shaft is carried in four plain babbitt, bronzed-backed bearings, a single ball bearing at the gear end, and one double-ball thrust bearing at the propeller end. This use of multiple bearings gives greater rigidity to the shaft, and by reducing the bending moments allows the use of the lighter shaft. The disadvantage is in the extra work necessary in fitting the extra bearings. The use of a ball bearing at the gear end gives slightly easier running qualities, otherwise there is no particular advantage gained. It has six balls in one race.

The hollow main and crankpin journals are closed at each end with screw plugs of steel. The propeller hub of standard form is machined from a nickel-chrome steel drop forging and is nickeled all over. The shaft is tapered and the hub must be carefully cut to gage to insure fitting. It is secured on the shaft by a long plain key and by a compound nut at the outer end, one section screwing to the shaft and the other locking with the first and screwing to the hub.

TABLE XXIV.—CLEARANCES

	Min., in.	Max., in.	Desired, in.
Main bearings:			
Diametrical clearances	0.0015	0.0025	0.002
Cheek clearance	0.085	....	....
Ball bearing:			
Diametrical fit on shaft	Light drive fit	0.0005	Loose
Diametrical fit in case	0.0005 (loose)	0.001	
End play with thrust	0.0005	0.0035	0.002 (loose)
Crankpin bearings:			
Plain rod	0.001	0.002	0.0015 (loose)
Forked rod	0.002	0.004	0.003 (loose)
End play:			
Plain rod	0.006	0.008	0.007 (loose)
Forked rod	0.008	0.010	0.009 (loose)
Wristpin bearings	......	0.26	0.002 (loose)

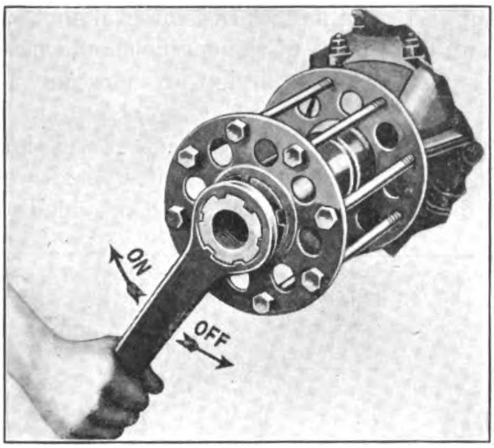

FIG. 300.—Removing or attaching propeller hub, models A, I and E.

The thrust bearing is of the compound type, taking both forward and backward thrust. It consists of two races, of 12 balls each, held apart by a plate and together by two removable collars which seat directly in the case, and must be free to turn in it to insure even wear on the balls. The whole assembly is held tight against the thrust collar, on the shaft, by a screw collar threaded to the shaft and seating in the case. The bearing should be a push fit on the shaft with a minimum clearance of .001 in. The fit of the screw collar in the case should be from .002 in. to .010 in. (loose).

204. Detail Specifications of Crankcase and Main Bearings. The case is of the deep-section type, the lower half providing an oil storage

sump, and carries the main bearings in transverse webs in both halves, as in the Liberty. This method gives a strong rigid support to the shaft, and bearings are easily fitted with a line reamer, but, when worn, cannot be taken up, and cannot be fitted with shims.

The upper half of the crankcase weighs 26 lb., the lower half, 31 lb. The length is only 3 ft. 2¼ in., showing the compactness of design. The width across supporting flanges is 14½ in.

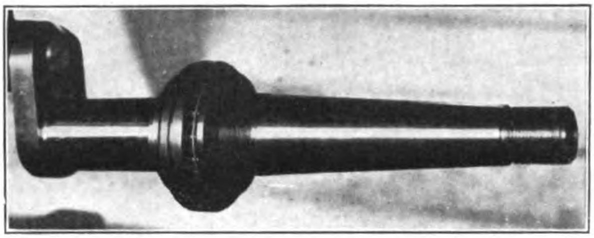

Fig. 301.—Thrust bearing, models A, I and E.

The case is supported on flanges cast integral along the lower edge of the upper half, and the weight of the engine should never be allowed to rest on any other part, since the design provides only for this means of support.

The two halves of the case are tied together with long through-bolts running through the webs from the bottom of the lower one to the top of the crankcase deck, two to each web, and provided with special nuts.

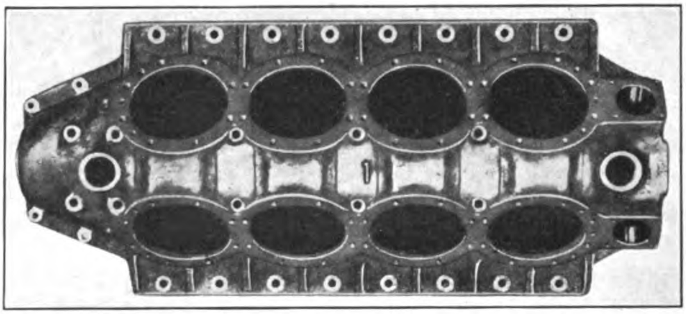

Fig. 302.—Crankcase, models A, I and E.

Also by studs, seating in the flanges and screwed tight against the under side of the lower flange.

Only one breather tube is provided, which is carried on the crankcase deck, at the gear end. It is fitted with a conical strainer and the removable cover, held by shackle bolts, has an annular ring of openings in the side walls near the top. Thus the opening is fixed, and not adjustable as on the Liberty, nor is the tube baffled, its position on the top of the case obviating the necessity.

The space between the gear end of the case and the first transverse web is separate from the rest of the case, as in the Liberty, and is called the gear chamber. It carries the auxiliary driveshafts, bearings, and gear trains, and provides a return for the oil overflow from the camshaft to the pump. The portion of the front wall of the case opposite the end of the crankshaft is open, and covered with a removable plate, giving easy access to the gear train and the ball shaft bearing.

Both halves of the case carry five transverse webs, the end ones being compound, which act as strengtheners for the case, and supports for

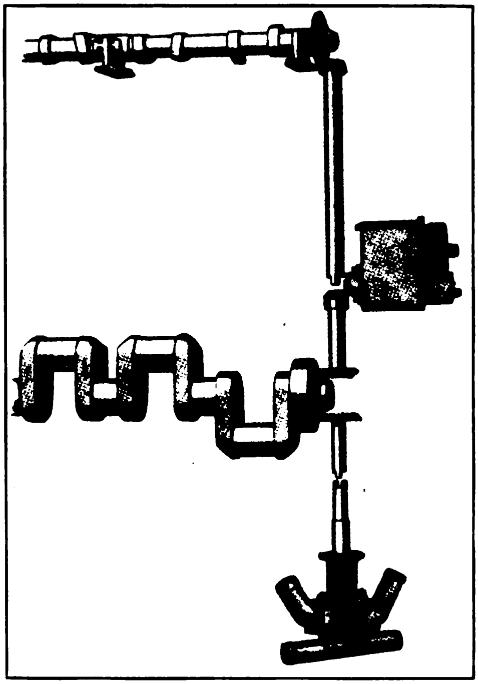

FIG. 303.—Magneto drive, model A.

the main bearings. The ones in the lower half of the case do not extend to the floor, but are bridged across, leaving one continuous storage sump in the lower part of the case. These webs carry the branch oil leads to the main bearings and also secure the main oil lead. A steel tube cast in place is inserted in the mold, in two sections brazed together to allow for contraction.

The four, plain, bearing bushings are of the ordinary split type, of babbitt, bronze backed, and are carried in the crankcase webs as described above. They are being prevented from end play by collars on each end, and the lower half secured against rotation by a set screw seating in the web.

With this arrangement shims cannot be used for fitting, as this would affect the lapped joint of the crankcase, and in fitting, it is necessary to see that the edges of the bushings do not project above the surface of the case.

The bushings having been fitted as described above, the halves of the case are bolted together and the bearings reamed out. The use of a line reamer with multiple adjustable cutters is preferable, but a single set of cutters may be used if the former tool is not available. In this case it is necessary to line each bearing, with the *first* one reamed, in order to keep the same line throughout and avoid the chance of multiplying an original error.

The only hand scraping necessary is a slight "touching-up" to remove any roughness left by the reamer, and to finish off the edges so that the fillets on the shaft do not bear on the bushings.

The reamer is usually turned by hand, but may be power driven. The fit is tested by an oversize mandrel whose diameter is that of the journal plus .0025 in.

205. Detail Specifications of Camshaft-drive Gearing. This assembly consists of two 2-piece special alloy steel shafts carrying casehardened bevel gears, the lower sections being carried in the gear chamber of the crankcase.

The drive gearing is as follows: a 24-tooth bevel gear, spline-connected to the end of the crankshaft, drives the integral 20-tooth bevel gears in the lower ends of the inclined shafts. On the upper end of these shafts integral 12-tooth gears provide for the magneto drive. The upper sections of the inclined driveshafts, carried in tubular steel housings, are connected to the lower halves by screwdriver joints, the tongues being in the upper sections. Integral 15-tooth gears on the upper ends of the driveshaft mesh with 36-tooth gears which are keyed to the ends of the camshafts. Taking the ratio of driving to driven gears, we find that the former have $\frac{24}{20} \times \frac{15}{36} = \frac{1}{2}$ as many teeth as the latter, and hence, the last drive gear of the train—the camshaft gear—travels half as fast as the first driven gear, that is, on the end of the crankshaft, speed being inversely proportional to the number of teeth, giving the required speed of the camshaft relative to crankshaft speed.

The valve timing is as follows:

Inlet opens	10 degrees P.T.C.
Inlet closes	50 degrees P.B.C.
Exhaust opens	45 degrees B.B.C.
Exhaust closes	10 degrees P.T.C.
Spark advance (fixed)	$20\frac{1}{3}$ degrees B.T.C.

The point of inlet opening, being that at which the cycle really begins, is called the *neutral point* and, in this engine, it will be noted that

it is also the point of exhaust closing, these events being simultaneous; a fact which aids materially in timing.

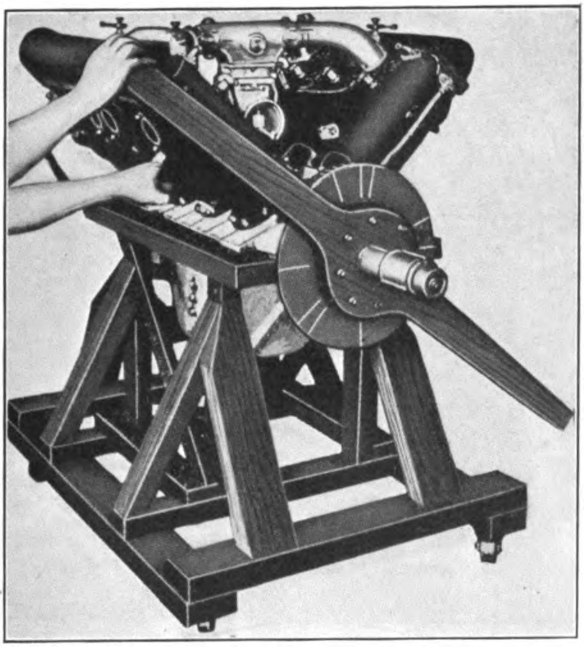

FIG. 304.—Finding top dead center, models A, I and E.

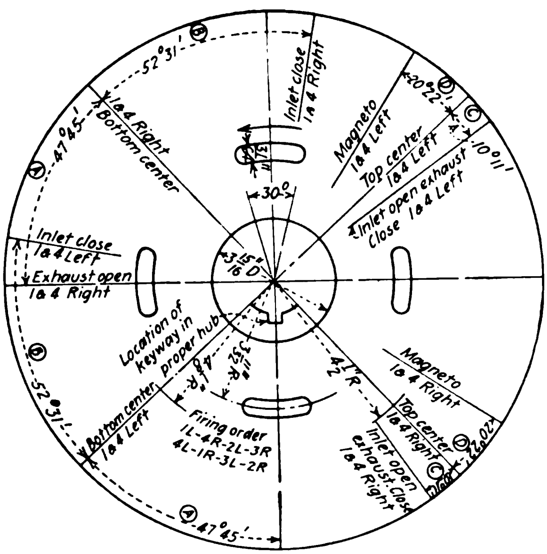

FIG. 305.—Timing disk, models A, I and E.

To time the valves in reassembly proceed as follows:

(*a*) Assemble driveshafts according to marks on gears.

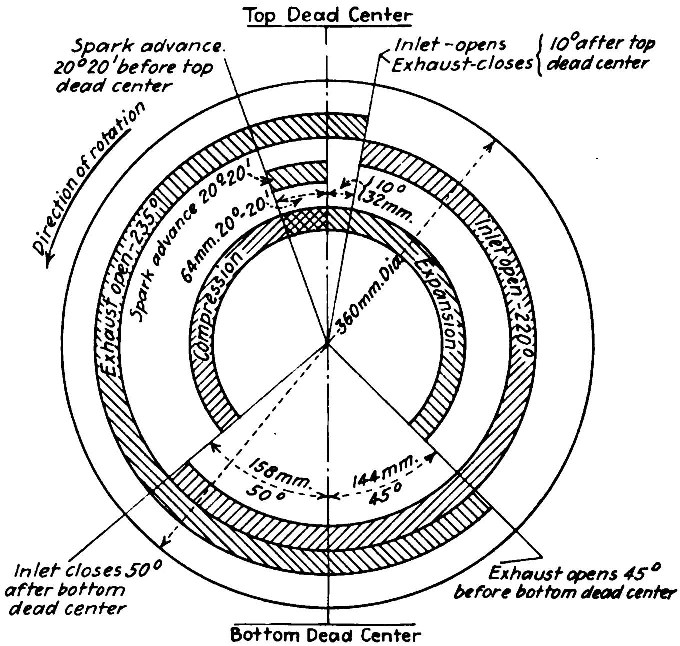

FIG. 306.—Valve and magneto timing, models A, I and E.

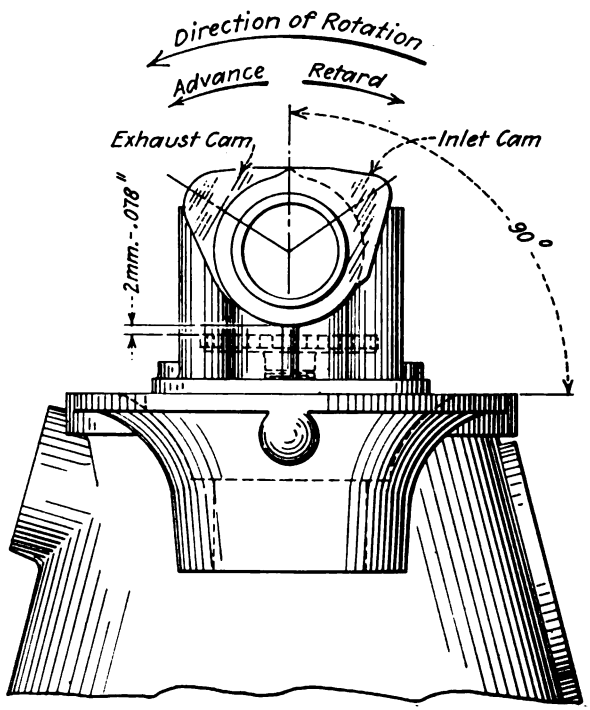

FIG. 307.—Position of cams when piston is at top dead center at beginning of suction stroke, models A, I and E.

(*b*) Set pistons Nos. 1L and 4L on T.C., No. 4L on the firing stroke.
1. Attached timing disk and marker.
2. Insert plug gage in spark-plug hole.

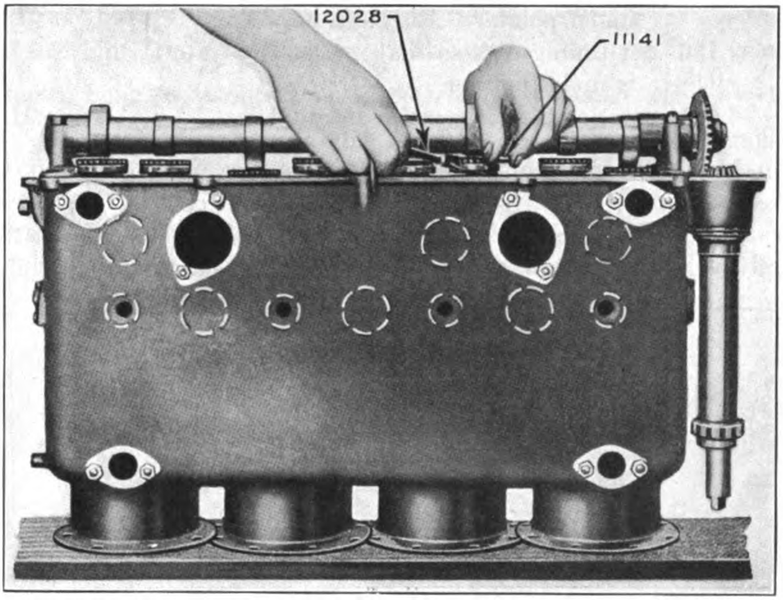

FIG. 308.—Adjusting valve tappet clearance, models A, I and E.

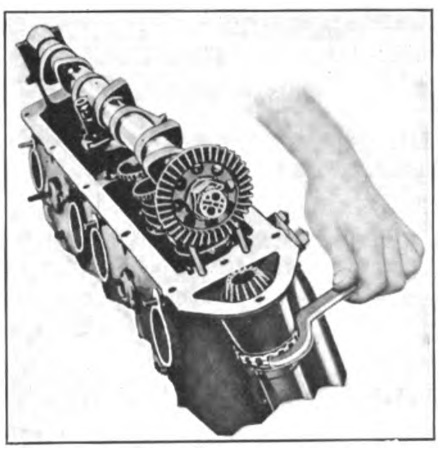

FIG. 309.—Raising or lowering vertical shaft casing, models A, I and E.

3. Turn crankshaft so that piston is coming up on either side, until crank is a few degrees B.T.C. Mark reading on plug gage, and under marker on disk.

4. Continue rotation in same direction, past mark on plug gage.
5. Turn crankshaft in opposite direction until mark on plug gear registers as in *c*. Mark reading on timing disk under pointer. Engine is on T.C.
6. Set timing disk so that mark T.C.—No. 1L and No. 4L—is under pointer.
7. Set No. 1L on *neutral point*, that is, "10-E.C.—No. 1L."

(*c*) Mount the camshaft, with its gear attached, so that the top faces of the cams are parallel to the tappet anvils on No. 1L, the noses of the cams pointing up. Tighten the 6 nuts on the 3 camshaft bearings securely, as a slight looseness will cause a considerable variation in timing.

FIG. 310.—Adjusting vertical shaft, models A, I and E.

FIG. 311.—Adjusting camshaft and gear, models A, I and E.

(*d*) Set valve tappet clearance by screwing anvils down, or up, by means of the special spanner wrench provided for this purpose, desired clearance being .079 in.

(*e*) To check valve timing turn crankshaft *back*, then *forward*, to take up backlash in gears, placing cigarette papers under cams, until *neutral point* is again reached. At this point the paper under the exhaust cam should begin to tighten (valve closing), and that under the inlet cam to loosen (valve opening).

If a new and unmarked camshaft gear is being assembled, proceed as follows:

1 and 2. As above.

3. Mount camshaft as above, but *without* drive gear.

4. As above.

5. Loosen nuts on camshaft bearings and raise shaft until gear can be slipped on, choosing that keyway in gear which allows meshing with

driveshaft pinion with the least disturbance of camshaft position. Replace shaft, meshing gear, and tighten nuts carefully as before.

6. Same as 5 above.

After setting camshaft, turn crankshaft through 90 degrees and repeat 2 to 6, as above, from right bank.

In case of faulty timing proceed as follows: The camshaft gear has 36 teeth, hence a variation of 1 tooth gives a change of $\frac{360}{36} = 10$ of camshaft rotation, or, since the camshaft travels at half crankshaft speed, = 20 degrees of crankshaft rotation. This correction is made *directly*, that is, in case of late timing the shaft with gear attached, is turned *forward* one or more teeth, as may be required.

The pinion in the upper section of the driveshaft has 15 teeth, and the screwdriver joint between the upper and lower section may be set

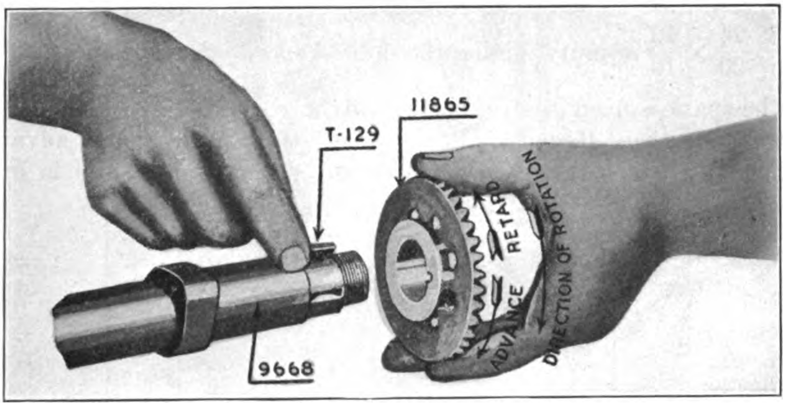

FIG. 312.—Adjusting gear on camshaft, models A, I and E.

in two positions, 180 degrees apart. Hence, half a revolution of the upper section of this shaft, the pinion and camshaft gear being out of mesh, will give a variation of half a tooth on the camshaft gear, 10 degrees. This half a revolution may be in either direction since the correction is an even half a tooth.

The camshaft gear is attached to the camshaft by a key on the latter. The key fits into any one of 5 equally spaced keyways in the gear and is secured by a castellated nut on the end of the shaft. The nut is locked with a cotter pin. By removing this gear and replacing it one keyway in advance, or retard, of its original position we move it $36/5$ or $7\frac{1}{5}$ teeth. Then the shaft, with gear attached, must be turned $\frac{1}{5}$ tooth, or $\frac{20}{5} = 4$ degrees in the *opposite direction* to that of original gear change to mesh with the driveshaft pinion. Therefore this gear adjustment is made *not directly*, but in the direction *opposite* to that in which it is necessary to

turn the shaft in order to effect the desired change in timing. In case of late valve timing move the gear *backward* one or more keyways, and then move shaft, with gear attached, *forward* the distance necessary to mesh.

206. Detail Specifications of Attached Accessories. *Ignition System. Magneto.* The two Dixie No. 800, non-wound armature type magnetos are used, each having a 4-winged rotor and a 4-lobed cam. They give four sparks per revolution. With the double ignition system used, the magnetos then run at engine speed, both rotating in an anti-clockwise direction. They are carried on bracket projections at the gear end of the crankcase, one at the end of each cylinder bank, and are driven by a 10-tooth bevel gear on the armature shaft, meshing with the 12-tooth gear in the upper end of the lower section of the inclined drive-shaft, as described above. The value of this gear train, taking the ratio of driving to driven gears, is:

$$\frac{24}{20} \times \frac{12}{10} = \text{unity, giving the desired speed or engine speed.}$$

The spark is fixed at $20\frac{1}{3}$ degrees advance.

Hand-starting Magneto. Because of this fixed spark advance, making starting without a *kick-back* almost impossible, and in order

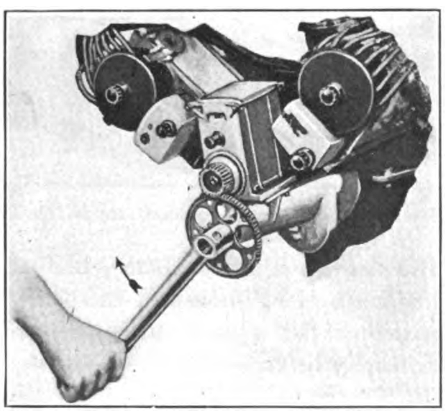

Fig. 313.—Hand-starting magneto in position, model A.

to give a hotter spark at low engine speeds than is possible with the main magnetos, hand-starting magnetos of special design are employed in this ignition system. The one used is the Dixie No. 100, a non-wound armature type having a 4-winged rotor and a 4-lobed cam, and hence giving four sparks per revolution of the armature shaft. It has no distributor of its own, but the high-tension lead is carried to a follower-arm on the distributor of one of the main magnetos, giving a safe degree of spark retard. It carries a steel point instead of a carbon brush,

and has about $\frac{1}{32}$ in. clearance from the segments, across which the the spark must jump. This lead is entirely insulated from the main high-tension lead, and when the hand-starting magnetos are to be used the main magneto must be grounded.

This magneto may be separately mounted and turned by hand, giving a shower of sparks in the cylinder on the firing stroke, or, it may be gear-connected to the hand-starting crank, usually about three to one.

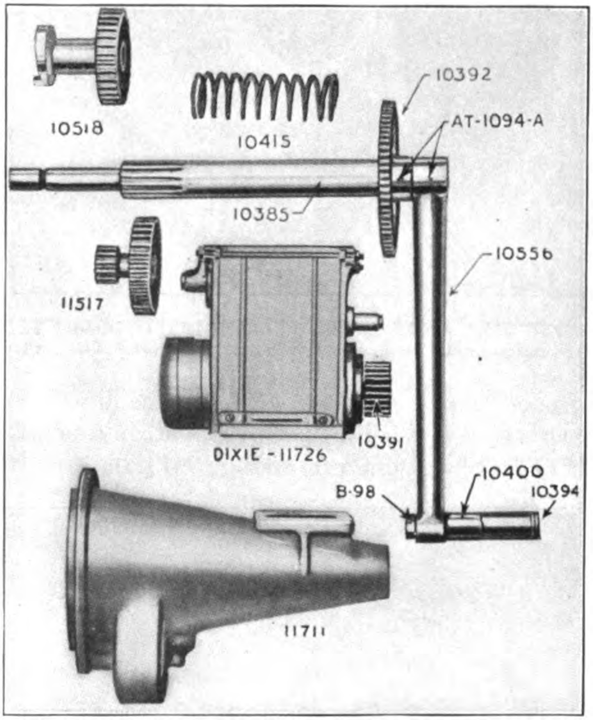

FIG. 314.—Hand-starting magneto, models A, I and E.

Carburetors. This engine is regularly equipped with one Zenith carburetor, model 48 D.C. Duplex, carried in the vee of the engine. Each barrel is directly connected to the inlet manifold on one cylinder bank, and hence, supplying four cylinders, the firing order being such that each barrel is drawn upon alternately, thus assuring even supply.

Specifications:

Barrel diameter	48 mm.—1.88 in.
Compensating jets	28 mm.—1.10 in.
Choke for:	
Warm weather	No. 150.
Intermediate	No. 160.
Cold	No. 170.
Main jet	No. 140.

The altitude adjustment will lean the mixture about 10 per cent. As an alternative the Stromberg NA-D4 Duplex carburetor can be supplied, carried in the same manner as the Zenith model.

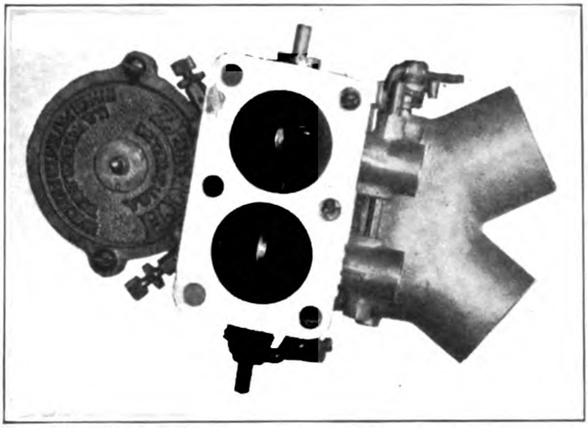

FIG. 315.—Zenith carburetor, model 48 D.C. (model A).

Specifications:

Barrel diameter	1.937 in.
Choke diameter	1.312 in.
Body metering nozzle	No. 46 drill.

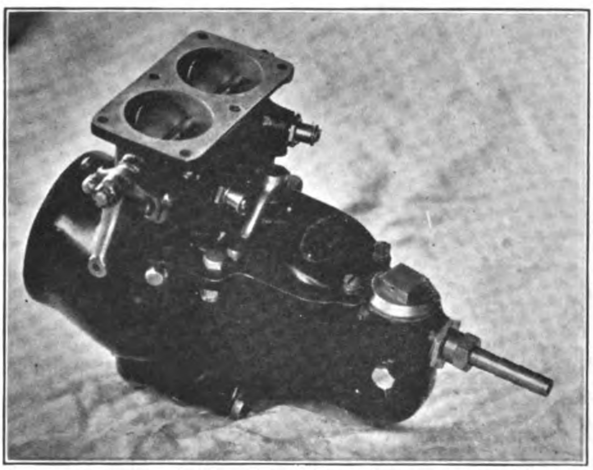

FIG. 316.—Stromberg carburetor, model NA-D4 (model A).

A discussion of air inlet position and of adjustments, will be taken up under the Liberty carburetors.

Oil Pump. This is of the sliding vane type, a modification of the ordinary centrifugal pump in which the cylinder is set eccentric to the

shaft, and the impellers instead of being fixed, slide in and out in grooves in the shaft. They are held against the cylinder walls at all times, by

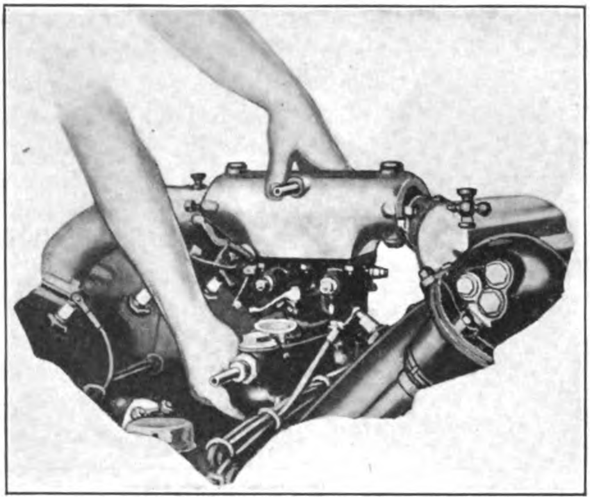

Fig. 317.—Removing carburetors and tee from engine.

spring action. The inlet consists of a vertical row of holes on the front side of the cylinder and the outlet is a similar row in the back side, connecting with the main oil lead. The oil pump is carried in the gear end of the lower half of the crankcase, and is driven directly from a vertical shaft, to which its shaft is spline-connected, gear-connected to the 24-tooth crankshaft gear described above. The reduction is

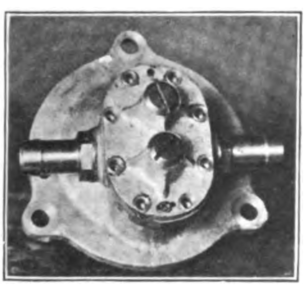

Fig. 318.—Oil pump, models A, I and E.

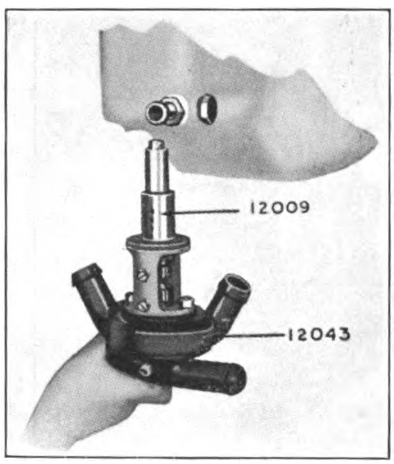

Fig. 319.—Method of assembling or disassembling oil and water pumps, models A, I and E.

$\frac{24}{20}$, so that the pump turns, in an anti-clockwise direction, at 1.2 crankshaft speed. At 1,450 engine r.p.m., that is, 1,740 pump r.p.m.

it will deliver 2.2 gal. of oil at 150° F. against a 50-lb. pressure. This pump is single acting, that is, it serves only as a delivery pump, drawing

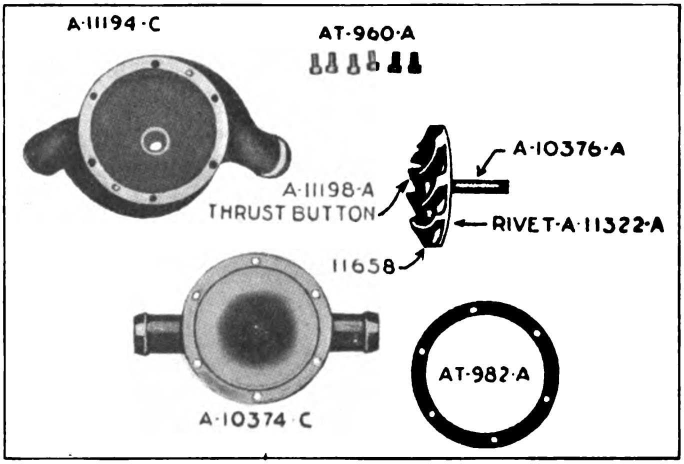

FIG. 320.—Water pump, models A, I and E.

oil from the bottom center of the sump reservoir, and delivering it to the main oil lead.

Water Pump. The water pump is of the centrifugal type with special impeller design, carried horizontally on the bottom of the gear end of the crankcase. Its vertical shaft is in line with the oil pump, and vertical driveshafts, and turns in an anti-clockwise direction at 1.2 times engine speed. It has two tangential outlets, one to each jacket casting, and two diametrically opposite inlets at the bottom, discharging together into the open center of the impeller wheel. Thus it has two inlet passages from the bottom of the radiator, or else one from each side radiator, the kind usually carried, and pumps simultaneously to each water-jacket casting, the capacity being 26½ gal. per min., with a free outlet at 1,450 engine r.p.m. or 1,740 pump r.p.m., water temperature being 120° F.

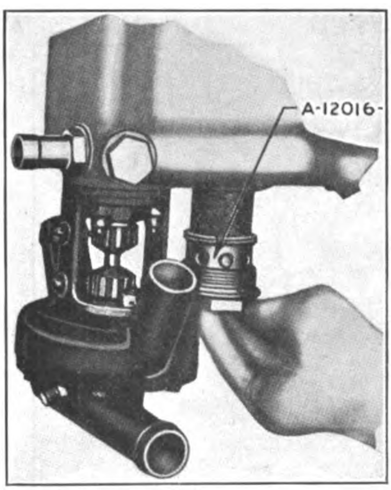

FIG. 321.—Water pump in position also showing oil strainer, models A, I and E.

Air Pump. The air pump is of the plunger type with automatic exhaust valve of bronze, carried on the right camshaft-housing-cover casting in line with the exhaust cam on No. 4L cylinder. It actuates a

spring which returns the piston as the cam pressure is released. An annular row of ports near the base of the cylinder provides the air inlet, and flexible tubing carries the compressed air from above the exhaust valve to the fuel tank. The piston, or plunger, consists of a leather dish, seating on a collar on the plunger shaft. It is held in place, and against bending, by a metal stiffener plate above it, the construction being similar to that of the ordinary hand air pump plunger. It is necessary to keep this leather piece well oiled, soft and pliable at all times. This pump furnishes the air pressure in the fuel tank necessary to insure a constant and steady flow of gasoline to the carburetors at a higher level. Its capacity is 10 lb. at 1,450 engine r.p.m. or 725 pumping strokes per min.

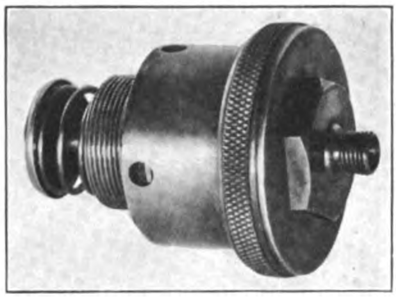

FIG. 322.—Air pump, models A, I and E.

207. Detail Specifications of Detached Accessories, Fuel Supply System, Cooling System and Lubricating System. *Detached Accessories.* The following detached accessories are used in this engine:

Radiators. Radiators of the side type usually carried on each side of the fuselage.

Fuel Tanks. No information available on this subject.

Oil Tanks. No information available.

Supply Pump. No supply pump is used, the gasoline being fed under air pressure.

Instruments. Engine instruments are discussed under Liberty accessories.

Battery. No battery is used.

Starters. Starters are considered under Liberty accessories.

Auxiliary Pump. No information available on this subject.

Fuel Supply System. There is at present no information available on number, size and location of tanks, or connections to carburetor. The supply to the carburetor is positive, an air pressure of 2 lb. or less, being carried in the air storage tank.

The carburetors are direct-connected to the cross member of the manifold system, an aluminum casting carrying two separate elbow passages leading from each carburetor barrel to the external manifold on that side. This section carries the mixture fore-and-aft to points midway between cylinders No. 1 and No. 2, No. 3 and No. 4, in one cylinder jacket casting. From this point the inlet passages are cored-out openings in the jacket casting, leading to the inlet valve cages of the adjacent cylinders which, it will be noted, are together, so that even distribution to all cylinders is affected.

The cross member carrying the elbow passages is water-jacketed, has two inlets, one from each cylinder-jacket casting, taken off at the upper side at the propeller end, and one outlet to the radiator line. This provides an effective means of heating the mixture, for, since the jacket is around the elbow passages, the disturbance of mixture flow which may occur there only serves to throw more of the mixture against the heated walls, and so facilitates the transmission of heat to all parts of the gas.

Cooling System. The water pump, as has been shown, delivers water to each of the two jacket castings separately, the inlet connections from the pump being at the gear end in the lower outside face. The rest of the circulation is effected through the cored-jacket passages in the block

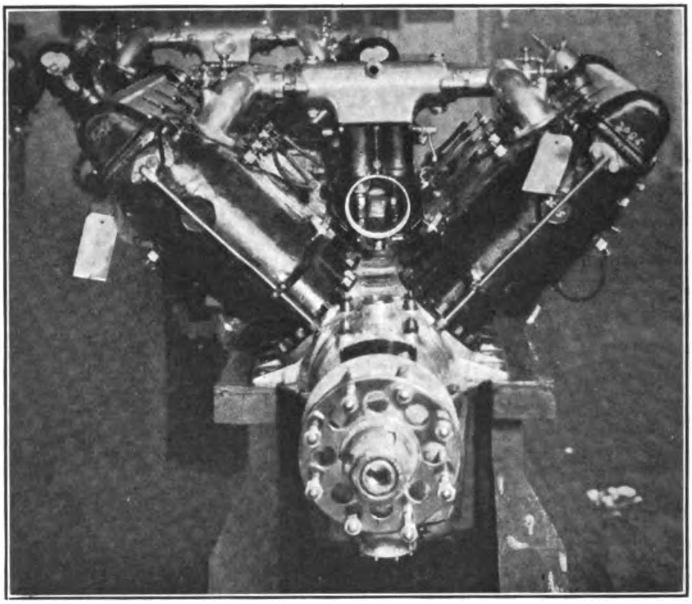

FIG. 323.—Carburetor inlet manifolds in position, models A, I and E.

casting. These passages extend around each cylinder, and around the valve cages, but not directly over the cylinder head, and only partially around the stem guides. The outlet is at the propeller end, on the upper inside. The maximum water temperature is 190° F., but the desired maximum is only 100° F., and the engine tests at the factory are made with temperature of from 100° F. to 110° F. Satisfactory results are obtained, however, with temperatures of around 160° F., which corresponds to standard practice. Since the valve stem guides get little aid from the cooling water in dissipating their heat, the oil bath, in which the upper portion of the valve stems run, is depended upon for the greater part of the cooling effect, and oil temperature is a vital factor in satisfactory valve performance in this engine. This will be discussed later.

Lubrication System. This engine is designed to run with a wet sump, that is, the main oil storage is in the lower section of the crankcase, although, when an oil radiator is used the sump is kept dry, as will be described later. With the wet sump system the circulation is as follows:

(*a*) The pump draws the oil from the sump, the inlet connections being in the bottom-center of the case directly above the drain plug.

From the discharge side of the pump it goes through a cored passage in the case, through the removable cylindrical screen just behind the pump proper, then to the tubular steel main oil-lead in the lower half of the case.

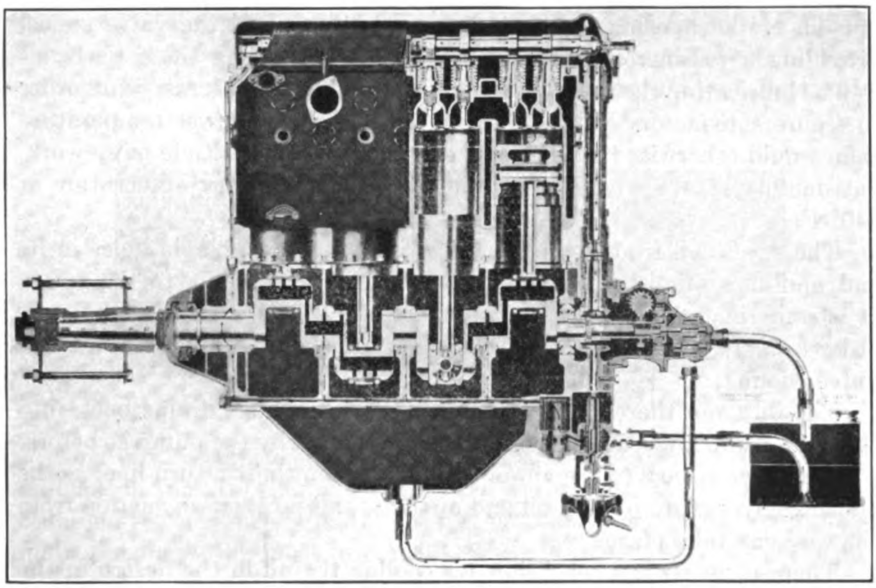

Fig. 324.—Lubrication chart, model A.

(*b*) Branch leads from the main lead pass up through the lower-case webs and enter the main bearings top and bottom through radial holes in the bushings. The bushings or radial holes are connected by a passage on the back of the bushings between them and their seats.

The excess oil passes into the hollow main journals, through radial holes and is forced up through leads drilled in the crankcheek, by the centrifugal force into the hollow crankpins. It passes out through radial holes in these pin journals to the crankpin bearing surfaces, and then through holes in the bearing bushing to the outer side of the shell, lubricating the forked rod bearing. The excess oil from these bearings is whirled off in a spray, or fog, lubricating the cylinder walls and wristpin bearings. The *wiper* rings at the bottom of the piston skirts facilitate in properly distributing this oil film on the walls. The propeller end of

the main lead is provided with a removable screw-plug for the pressure-gage connection and this gives access for cleaning. The lead to No. 5 main bearing divides just below it, so that the excess oil passes around the bearing bushing and up through a cored passage in the web to a connection, on the crankcase deck, to two external tubes which carry the oil up the end of each cylinder block to the camshaft housing. It enters first the No. 3 bearing bushing, in the usual manner, through a radial hole in the journal into the hollow shaft. Radial holes in No. 2 and No. 1 journals provide for the lubrication of these bearings and similar holes in the backs of the cams allow the escape of oil over their faces, cutting down tappet friction. The excess from the bearings and cams collects in the bottom of the housing and forms an oil bath around the valve stems, providing a reasonably satisfactory method of cooling these parts, as well as lubricating the stems in the guides. Thus it is necessary, in order to secure satisfactory valve life to keep the oil at a lower temperature than would otherwise be necessary, especially in low altitude navy work. Satisfactory results were obtained at Pensacola with the temperature at 140° F.

The excess oil from the camshaft passes out through six holes in its end and flows down, over the driveshaft and gear train, to the sump. It is sometimes found necessary to plug one or more, of these holes in order to increase the amount of oil in the camshaft housing and so aid in valve cooling.

The oil from the cylinder walls and main bearings drains back into the main sump underneath, from which it is drawn by the pump as before.

It is unnecessary to use an oil trap in the camshaft return line, as the housing cover-plate joint is oil and airtight, and no *breathing* action from the case can take place.

There is no special provision for cooling the oil in the design of the engine, and this creates quite a problem in navy practice where the work is all at low altitudes. To meet this need the Wright-Martin Company furnished a so-called *oil radiator* which was nothing more than a plain rectangular tank carried in the bottom of the fuselage with its lower surface exposed to the air stream. Its action was not satisfactory. At Pensacola a radiator of copper tubing has been designed, and installed in the propeller stream, which is proving satisfactory. It keeps the oil temperature at 140° F. at elevations of a few hundred feet, with wide open throttle. Any such external storage necessitates running with a dry sump and installing a pumping device, to drain the sump and deliver oil to the external tank or radiator. A two gear pump, similar to that on the Curtiss OXX, is carried on the gear end of the crankcase, its shaft being directly connected to the engine crankshaft. An external suction line connects with the bottom center of the crankcase, through the drain plug, the main pump suction line being plugged, the discharge carries the

oil to the radiator or tank. The main pump suction line is then connected to the radiator, and the pump discharges in the usual manner. This system is now standard in Models *I* and *E*.

The pressure-release valve is located in the left side of the lower half of the crankcase, at the gear end, in a bypass off the cored passage from the discharge side of the pump to the main oil lead. It consists of a flat plunger backed by a helical spring, held in place by a cap, which screws into the case. It is not adjustable, but the spring tension is such that the plunger will release the oil at from 50 lb. to 75 lb. per sq. in. pressure, with a temperature of 150° F. and crankshaft speed of 1,450 r.p.m. Care should be taken that no foreign substance lodges under the seat and causes loss of oil on return to sump, and a consequent drop in pressure. The retaining cap is removable by a special wrench provided for the purpose, and allows complete removal of the spring, plunger and seat, for inspection and repair.

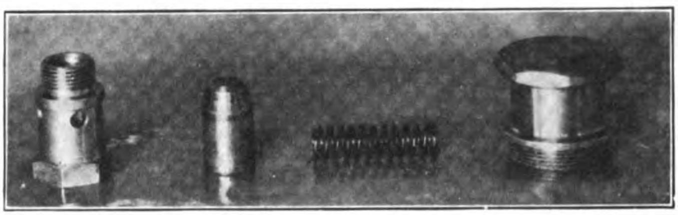

FIG. 325.—Oil pressure release valve.

The oil-pressure gage connection is located at the end of the main oil lead, in the propeller end of the crankcase. This is proper, as here is obtained the pressure after the oil has passed through three of the four main bearings—the most important single function it has to perform—and if the pressure registers correctly here it is a sure indication that it is correct up to this point. A better location would be behind the fourth main bearing, as is done in the Liberty engine.

The oil-temperature gage connection is taken off of one of the oil level gage plugs in the right side of the lower half of the crankcase. Both recording instruments are located on the cockpit, in full view of the pilot at all times.

The amount of oil used is 3 litres (approximately 3 qt.), every hour of flight with wide open throttle. The level in the sump should never come above the second gage plug on the right side of the case or 10 litres, as there is danger of fouling the spark plugs when more is carried. The first gage plug shows 7 litres.

The oil used should meet the following specifications:

Flash point (open cup) = 465° F. (min.).
Burning point = 520° F.

Viscosity	(Saybolt)	= (107–112) at 210° F.
	(Tagliabue)	= (110–115) at 212° F.
Specific gravity		= .886.
Cold test		= 40° F. (Max.).

Castor oil, the better grade of Liberty oil (petroleum base), and some grades of Wolf's Head oil, come under these specifications, and may be used satisfactorily.

The delivery of the pump at 1,450 r.p.m., with oil at 150° F. is about 2.2 gal. per min. Therefore, with a full supply, 2.64 gal., the rate of turnover is $\frac{2.2}{2.64}$ = .83 times per min.

The maximum allowable temperature is 200° F. but this is too high to insure proper valve cooling when operating with wide open throttle at low altitudes, as is done in navy work.

The desired temperature, in any case, is not over 160° F., but this cannot be maintained under Navy conditions without some added means of cooling the oil. As stated above, the Wright-Martin oil radiator is not satisfactory, but with the Pensacola copper tube type, no difficulty has been experienced in keeping the oil down to 140° F., giving reasonably satisfactory results as regards valve life. The pressure at 1,450 r.p.m. with oil at 150° F. should be 50 lb.

Hispano-Suiza Engine, Model I

208. Comparison of Models. *General Specifications.* This engine is similar to the Model *A* except in weight. The weights are as follows: weight of engine complete with attached accessories is 470 lb. Weight per rated horsepower is 3.13 lb.; and weight per cubic foot displacement is 1,130 lb.

Performance Figures. Similar in all respects to Model *A*.

Detail Specifications. This engine differs from the Model *A* only in the following parts.

Valves. The solid section of the valve stem, just above the head has been increased in diameter, from ⅜ in. to ½ in., giving a better heat path thus keeping the valve cooler.

The piston is of the solid-head type without cooling ribs, ⅜ in. thick at the head. The sides taper down from ⅜ in. at the top to ⅛ in. at the bottom. The rings are the same as in Model *A*, except that an additional lock-ring is provided for the full-floating wristpin. In the later engines of this model the pin is held in the bosses by an aluminum plug, as on the Liberty. There is no change in the construction of the wristpin itself.

Connecting Rods. The big end construction of the connecting rods has been changed somewhat. One rod is forked at the bottom end, as

before, but now has a two-piece bronze box, babbitt lines, bolted to it by four bolts. This bears directly on the crankpin journal. The plain

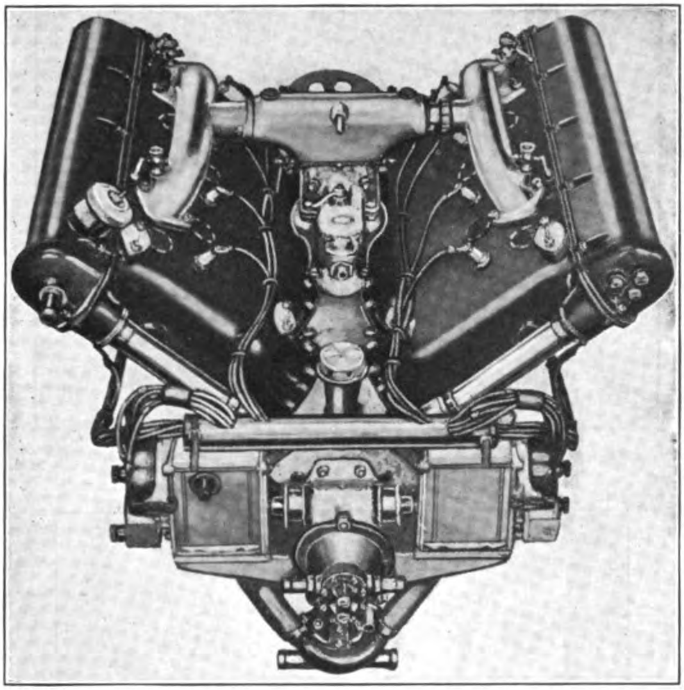

FIG. 326.—Rear view of models I and E.

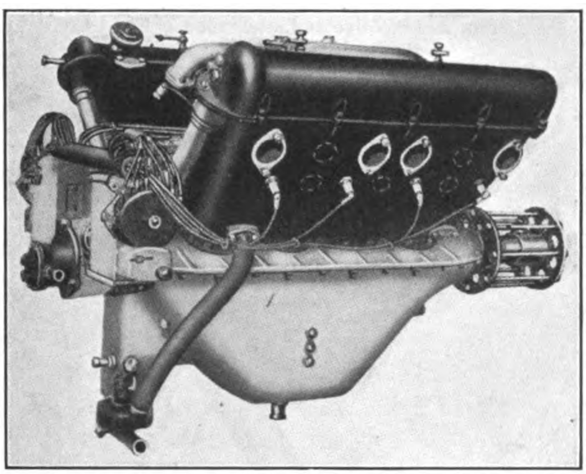

FIG. 327.—Right side view of models I and E.

rod bears on the outer and central portion of the bronze box. It will be seen that this construction is very similar to that on the Liberty, a

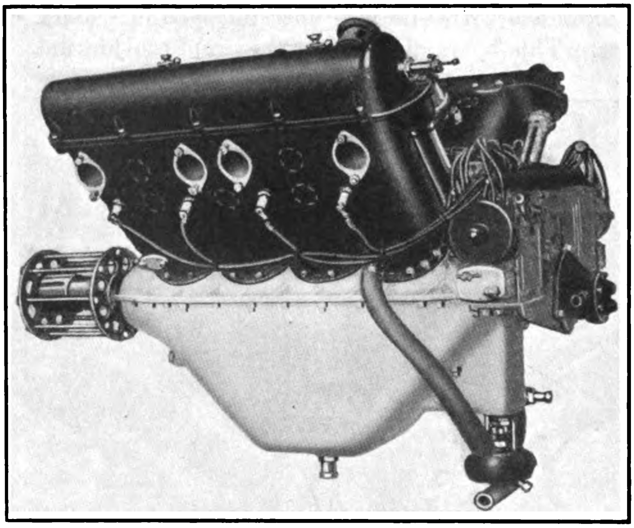

Fig. 328.—Left side view of models I and E.

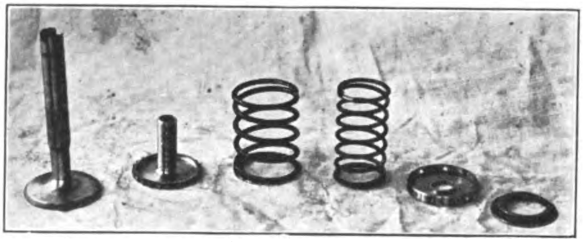

Fig. 329.—Valve and stem, models I and E.

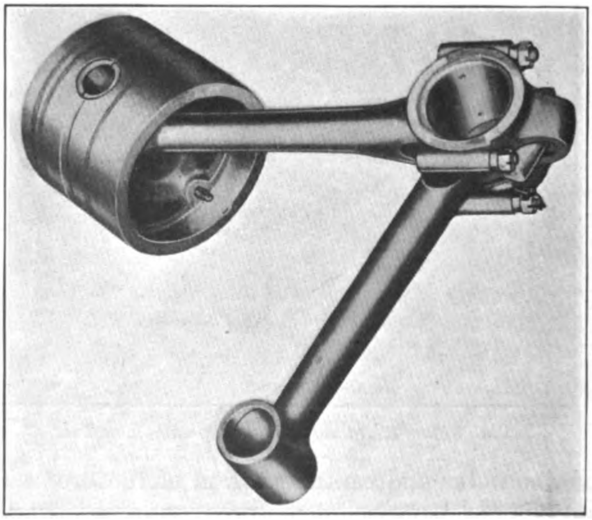

Fig. 330.—Piston model I.

bronze bearing being permissible for the outer rod since its relative motion on the forked rod is oscillatory and not rotating.

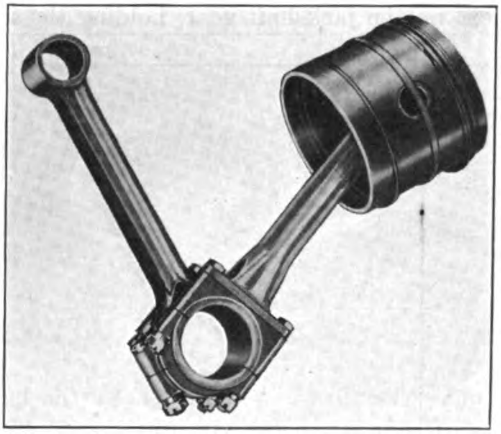

FIG. 331.—Piston and connecting rod assembly, models I and E.

Attached Accessories. Magnetos. Two Dixie No. 800 magnetos are used as before, but the support and method of drive are somewhat different. They are now carried transversely on a bracket attached to the

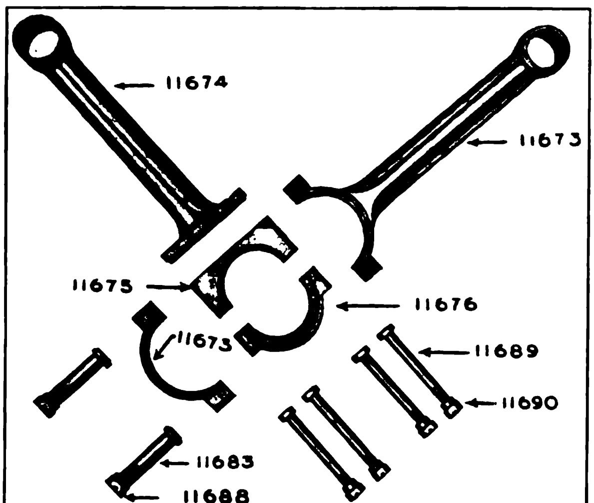

FIG. 332.—Connecting rod, models I and E.

gear end of the crankcase, with the driving ends facing inwardly. A jackshaft, in line with the crankshaft and driven from it through a screwdriver joint, projects in front of it and is carried at its outer and in a ball-thrust bearing which seats in the lower part of the bracket casting.

This shaft carries a spiral gear which drives a transverse shaft above it, and in line with the magneto armature shafts, through a worm. The direction of the spiral threads is such that the bearing pressure is on the front side of those on the jackshaft gear, holding the screw-driver joint

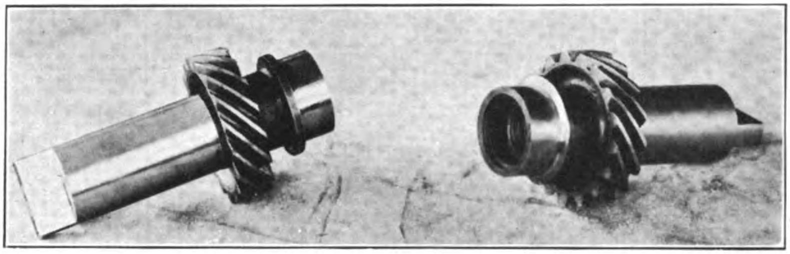

FIG. 333.—Detail of magneto drive, models I and E (side view).

in mesh at all times, the thrust being taken by the ball-shaft bearing. This transverse shaft has, at each end, a collar with 23 teeth, the male members of two splines. The inner ends of the magneto armature shafts also have similar collars with 24 teeth. A coupling, carrying the

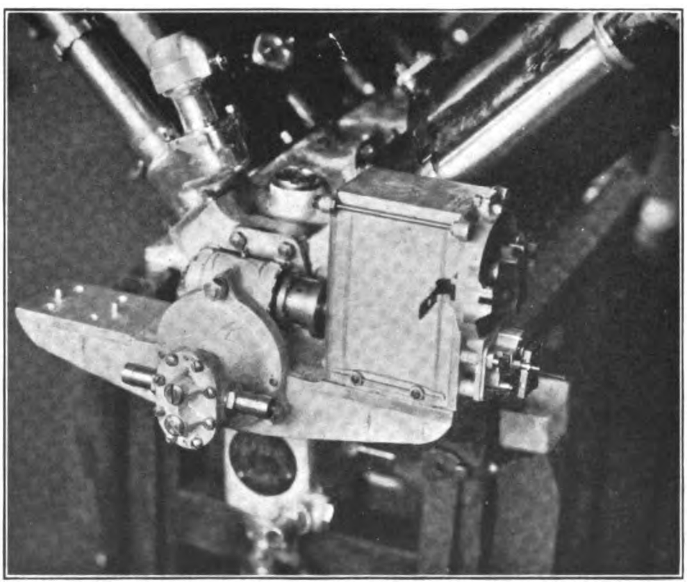

FIG. 334.—Detail of magneto drive, models I and E (end view).

female members of these two splines, is held in place by an inside spring which presses against a floating plate bearing against the inner end of the coupling and the collar on the armature shaft. A cotter pin through the coupling passes between the ends of the armature and driveshafts,

locking the coupling in place. The magnetos travel at engine speed and therefore, when they are synchronized, there are 23 × 24 chances of coupling the armature shafts to the drive shaft without disturbing the

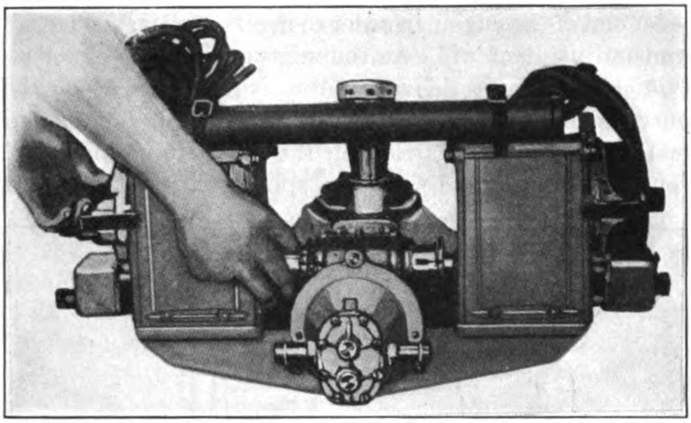

FIG. 335.—Timing magneto to engine, models I and E.

position of either the former or the latter. The possible correction for faulty magneto timing is $\frac{360}{23 \times 24} = 0.65$ degrees.

Carburetor. This engine is equipped with a Stromberg carburetor, Model NA-D4 of the following specifications:

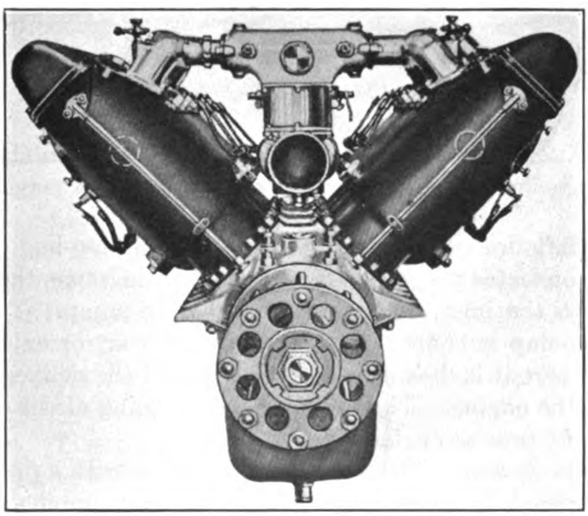

FIG. 336.—Front view, showing carburetor in position, models I and E.

Barrel diameter	1.937 in.
Choke diameter at throat	1.312 in.
Body metering nozzle	No. 46 drill.
Accelerating metering nozzle	No. 44 drill.

The carburetor has twin barrels fed from a common float chamber as on the Zenith Duplex models. Each barrel feeds one cylinder bank. The gasoline level should be approximately 30 mm. or $1\frac{3}{16}$ in. below the junction of the halves of the carburetor. The air inlet should face toward the propeller end of the engine in order to insure positive feed at all speeds. The altitude adjustment will lean the mixture about $33\frac{1}{3}$ per cent.

Oil Pump. The main delivery pump is the same as on the Model *A*, but since this model runs with a dry sump, a drain pump is necessary. A two-gear pump is used, carried on the magneto supporting bracket, and driven by a shaft in line with, and spline-connected to, the magneto

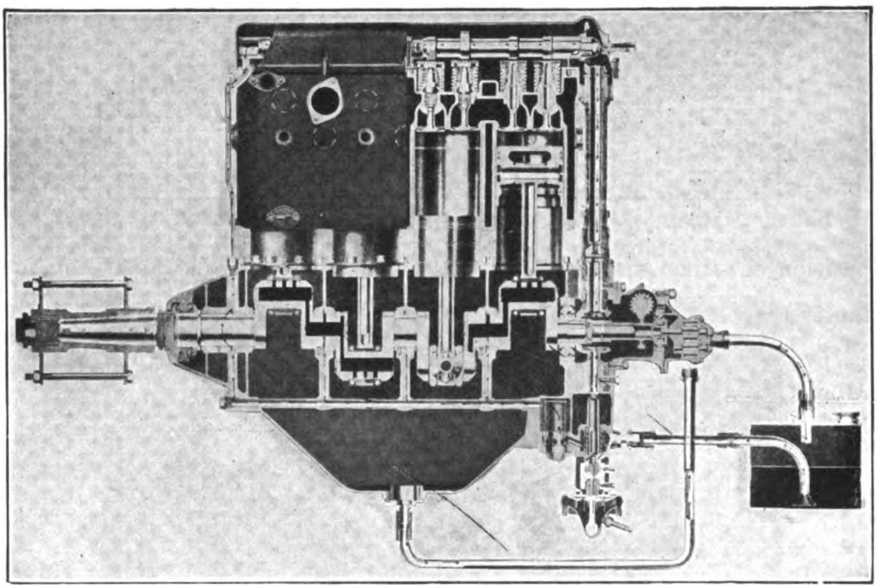

Fig. 337.—Lubrication chart, models I and E.

drive jack-shaft described above. The sump suction-line of the main pump is disconnected and an exterior line from the same, the sump drain plug is run to the inlet connection of the drain pump. The discharge side of this pump is connected to the oil reservoir, or exterior storage tank, from where it is drawn by the inlet lead of the delivery pump and delivered to the engine. The drainage pump, being direct connected to the crankshaft, runs at engine speed.

Lubrication System. The Model *I* engine runs with a dry sump, that is, the oil storage is in a separate exterior tank, the pumping arrangement being as above.

The suction side of the main delivery pump is connected to the storage tank or oil radiator, and the discharge side to the main oil lead in the usual manner.

The excess oil from the cylinder walls and camshaft drains back into the crankcase sump, as before, but the oil drawn from the sump, in this model by the auxiliary drainage pump, is delivered to the exterior storage tank.

The oil is cooled in this exterior tank or oil radiator. The radiator has one side exposed to the propeller stream. In the radiator supplied by the Wright-Martin Company this exposed side is provided with cooling ribs, but the design is not efficient.

Hispano-Suiza Engine, Model E

209. Comparison of Models. *General Specifications.* This model has the same number of cylinders, similarly arranged, as the Models *A* and *I*.

It develops 180 hp. at 1,800 r.p.m. by using a compression volume ratio of 5.33 to 1.

The bore and stroke are the same as on the Models *A* and *I*.

The weight complete with attached accessories is 470 lb., the weight per rated horsepower is 2.61 lb., and the weight per rated horsepower per cu. ft. displacement is 1,130 lb.

The lower weight per horsepower is due to the fact that the power output is increased without an increase in actual weight. The displacement volume, however, is the same, and so the weight per cu. ft. displacement is the same as in the Model *I*.

Performance Figures. The gasoline consumption varies from .5 lb. per hp.-hr. to .52 lb. per hp.-hr., and the oil consumption will average about .031 lb. per hp.-hr.

Detail Specifications. Pistons and Wristpins. The pistons are the same as on the Model *I*, except that the wristpin bosses are carried lower in the skirt. This raises the piston in the cylinder, decreases the clearance volume and increases the compression-volume ratio. This results in a higher compression pressure, a higher mean effective pressure, and hence, increased power.

The wristpins are tubular in section and are of the full-floating type, being retained in the bosses by aluminum caps. These caps are pressed into the ends of the bosses. This construction is similar to that employed on the Liberty.

Attached Accessories. Magneto. The magnetos are the same as on the Model *I*, but with fixed advance of 25 degrees.

Carburetor. This model uses a Stromberg carburetor, Model NE-D4, of the following specifications:

Barrel diameter	2.18 in.
Large choke diameter at throat	1.50 in.
Body metering nozzle	No. 42 drill.
Accelerating metering nozzle	No. 30 drill.

The altitude adjustment leans the mixture about 33⅓ per cent.

Lubricating System. The oil pressure, with temperature of 150° F., is about 60 lb.

Liberty Twelve Engine (Navy Type)

201. General Specifications. The Liberty aircraft engine is a 12-cylinder, V-type, 4-cycle, water-cooled engine. There are two banks of

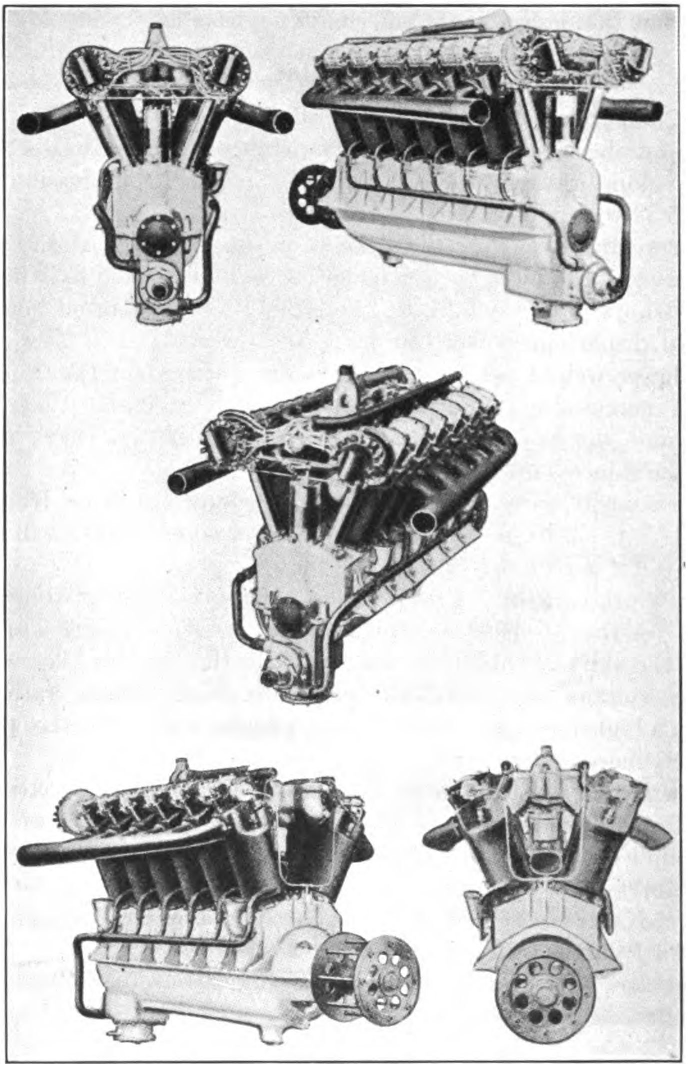

Fig. 338.—Views of Liberty engine.

6 cylinders each, the angle between the banks being 45 degrees. This is less than the customary V-angle for a 12-cylinder engine, it being

ordinarily 60 degrees, in order to give even firing impulses and hence steadier torque and less vibration. The change is made, however, to reduce the width of the engine and hence adapt it better to installation in the fuselage, as well as to cut down head resistance. The multiple

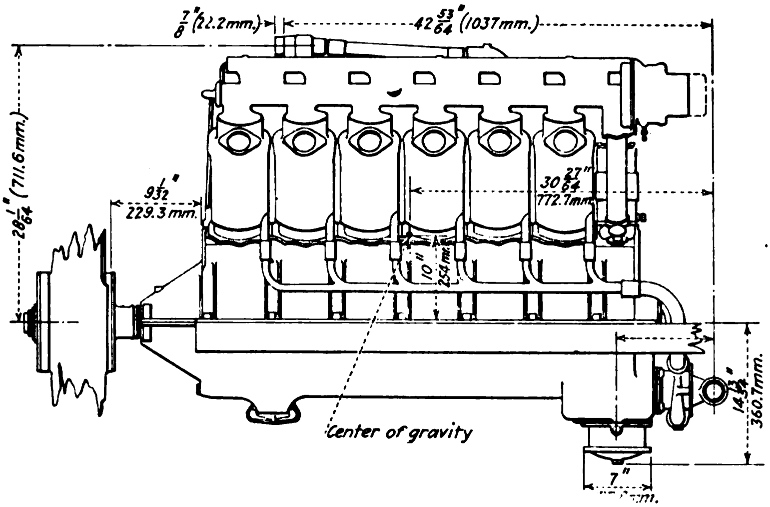

FIG. 339.—Side elevation of Liberty engine.

cylinders effectively smooth out the uneven spacing of the power impulses, so that on the whole, the arrangement is successful. Corresponding cylinders in each bank are directly opposite, thus cutting down the overall length of crankshaft and crankcase and so reducing weight.

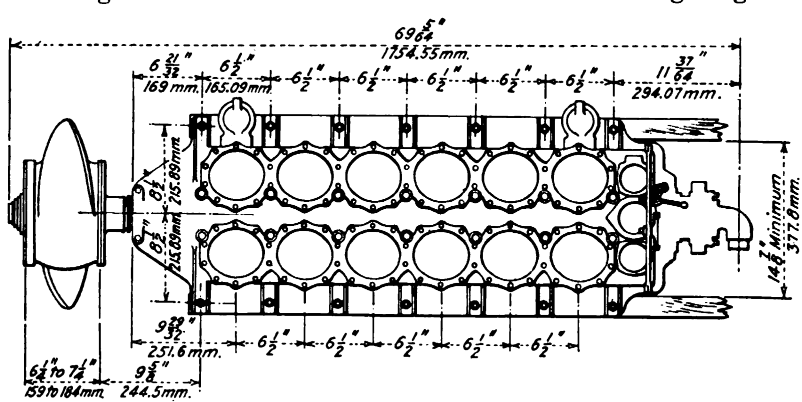

FIG. 340.—Top view Liberty crankcase.

The Navy type of this engine with its flat-topped pistons is rated at 385 hp. at 1,675 r.p.m. at sea level. The cylinder bore is 5 in.; the stroke, 7 in. The weight of the engine complete with attached accessories ready for shipment from the Packard test field at Detroit is 820 lb. This

gives a weight per horsepower of 2.131 lb. The engine has a total displacement of .956 cu. ft. and a weight of 858 lb. per cu. ft. displacement.

The firing order is: 1L, 6R, 5L, 2R, 3L, 4R, 6L, 1R, 2L, 5R, 4L, 3R, following the usual standard 6-cylinder firing order of 1, 5, 3, 6, 2, 4, in each bank, looking at the left bank from the gear end, and at the right bank from the propeller end.

211. Performance Figures. The power output varies greatly with individual engines as might be expected, the following table showing the averages of many tests at the factory of the Packard Motor Car Company.

Hp.	R.p.m.
383	1,676
372	1,663
330	1,600

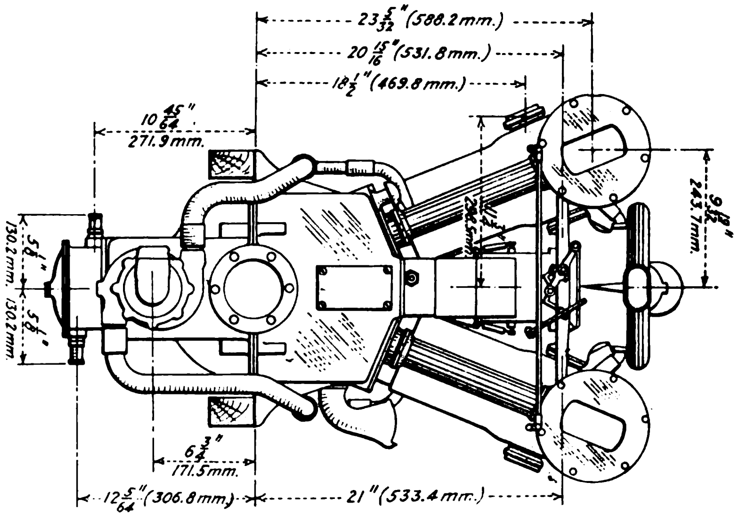

FIG. 341.—Distributor-end view Liberty engine.

Engines are passed in the factory inspection which show a power output of 360 hp. at 1,700 r.p.m.

The fuel consumption varies and is uniformly high for this type of engine. Actual figures from air station practice follow:

Liberty engine No.	Lb. per hp -hr. (with wide-open throttle)	Place of test
13	0.543	Pensacola
32	0.549	Pensacola
Average of 210 engines	0.586	Detroit

These results are rather high in view of claims for rates of .52 lb. per hp.-hr., and the average is probably nearer .55 or .56 lb. per hp.-hr. Some well run-in engines have shown consumption figures as low as .50 lb. per hp.-hr. but this is exceptional.

Engine No.	Lb. per hp.-hr.	Place of test
13	0.0305	Pensacola
32	0.041	Pensacola
Average of 210 engines	0.0245	Detroit

An average oil consumption of Liberty engines at air stations is between .030 and .035 lb. per hp.-hr.

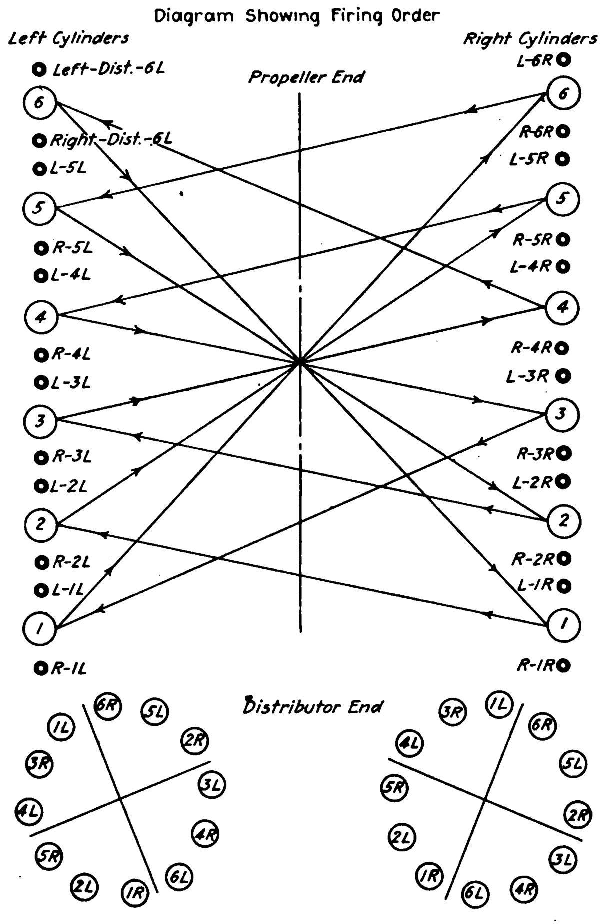

FIG. 342.—Diagram showing firing order.

212. Detail Specifications of Cylinders. The cylinder of the Liberty engine is of the valve-in-the-head assembled type, valve cages and water-jackets being separate and attached by welding to the machined barrel.

The barrel, including the integral head and hold-down flange, is of steel of a secret composition. The walls are .18 in. in thickness and have eight annular rings of tapered section spaced ¾ in. apart to give addi-

tional strength and aid in the circulation of cooling water by lessening the tendency of the water to flow directly up the side of the jacket from inlet to outlet, instead of following the proper spiral path around the cylinder. A heavy flange is cut $1\frac{1}{4}$ in. above the hold-down flange to provide a support for the welding of the lower edge of the water-jacket. The skirt of the barrel extends $2\frac{7}{8}$ in. below the cooling flange in order to provide a guide for the piston skirt at the lower end of its stroke as this construc-

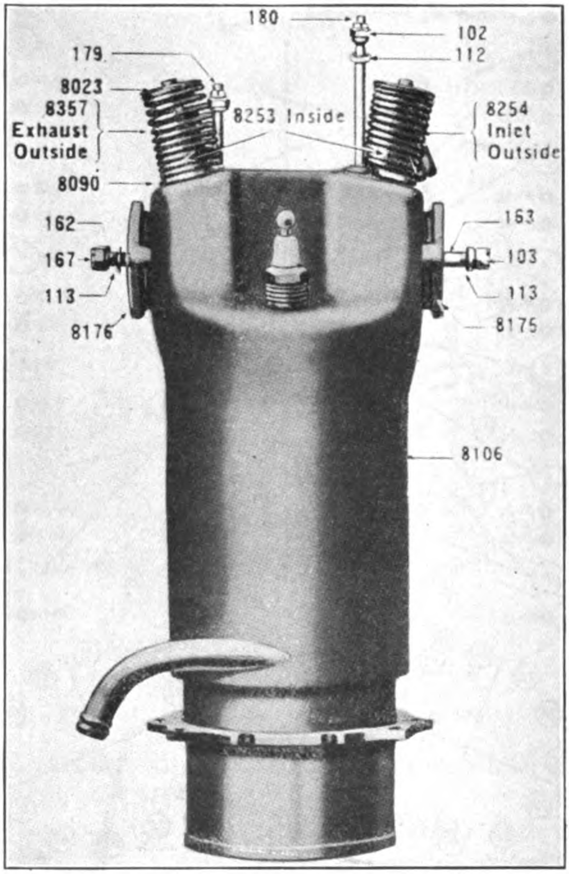

FIG. 343.—Liberty engine assembled.

tion decreases the height of the cylinder above the crankcase. The lower edge of the barrel is beveled on the inside to facilitate fitting the piston. The hold-down flange, $\frac{1}{4}$ in. in thickness, is machined from an upset portion of the blank and drilled for 10 stud holes, the two in the fore-and-aft sides of the flange being merely slots to receive studs common to adjacent cylinders.

The combustion chamber is flared at an angle of 15 degrees from a

point $11\frac{1}{8}$ in. above the lower end, the lower edge of this flare being counter-bored to form an angle of 30 degrees in order to provide an over-ride for the piston rings to prevent cutting and scoring of the cylinder walls. The head of the cylinder is dome-shaped and carries the valve and spark-plug seats.

The jacket is of Russian iron and consists of two symmetrical stampings which are welded together to the previously mentioned flange at the bottom and to the valve ports and cages at the top. This construction is light and cheap and assures even water space at all points in the jacket.

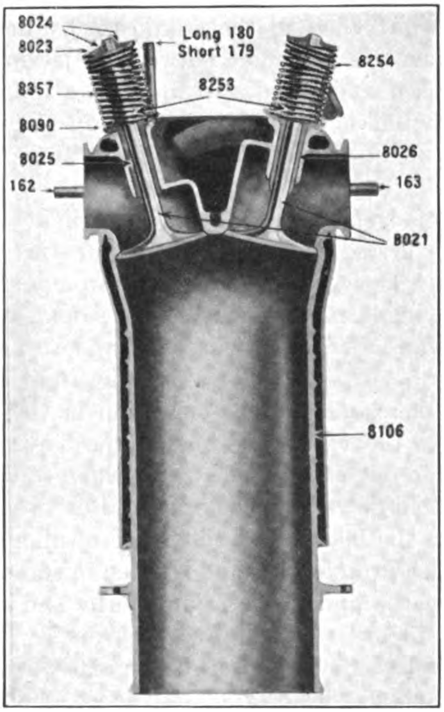

FIG. 344.—Section Liberty cylinder assembly.

The jacket is continued well down in the barrel in order to cool more effectively this often-neglected part.

The extreme height of the cylinders from top of water jacket to the crankcase deck is $13\frac{3}{4}$ in., while the projected or effective perpendicular distance above the crankcase at its highest point is $12\frac{5}{8}$ in. The diameter through the combustion head is $7\frac{1}{2}$ in. between centers. The weight of the complete assembly without valves and springs is $19\frac{1}{2}$ lb. while the stripped barrel weighs $11\frac{1}{2}$ lb.

The valve seats are of the beveled type, the angle being 30 degrees instead of the customary 45 degrees. In spite of the resulting thin

edge of the seat, no trouble has been experienced from overheating and consequent warping of the head or seat.

The valve cages and ports are machined in and out from separate steel forgings and welded into place in the cylinder heads. The port flanges are also separate and welded to the cages. It will be noticed that in a construction where the valve seat is in the cylinder head, the weld of the joint between cage and head is protected from the intense heat of combustion, thus giving a safer and stronger construction.

The spark-plug seats are drilled and tapped in the bosses in the cylinder head, on a diameter at right angles to that of the valves.

The cylinder is attached to the crankcase by means of ten 3/8-in. studs, two of which are common between adjacent cylinders. Castellated nuts are used and are drawn up with a uniform pressure and cottered. Nuts should never be backed up in order to fit a cotter, but new ones should be tried until a fit is obtained under the proper pressure.

The barrel is made from seamless steel tubing which is cut off in 4-ft. lengths, thus giving enough material for two cylinders. These sections are cut at a 45-degree angle to give two equal half sections and V-shaped cuts are made in each side to take out surplus metal. The truncated end is then heated to a white welding heat and forged in a bulldozer to form the head, the higher side being folded over and fused. Another heat is taken and another operation in the bulldozer flattens the head and forms the valve-cage bosses, the flare of the combustion chamber being rolled out at this time. The valve and spark-plugs seats are drilled. The hold-down flange is produced by upsetting the metal at the proper place in the blank. At this stage of manufacture the cylinder blank looks like a drop forging and is often mistaken for one by those who have not seen the above operations performed at the Ford plant where all cylinder blanks to date have been made. By this method of manufacture the cost of a cylinder has been greatly reduced.

The blank is machined, inside and out, the ribs, hold-down flange and lower water-jacket flange being formed and the combustion chamber shaped. The stud holes in the hold-down flange are drilled and the surplus metal removed in a milling machine. The spark-plug seats are drilled and tapped. The valve cages after being machined inside and out are welded to the cylinder head, first being spotted in two places by the electric arc and finished by the oxy-acetylene flame. The port flanges are electrically welded to the valve cages and then the water-jacket is fitted into place and welded together and to the cylinder flange, spark-plug seats, bosses, valve cages and port flanges by oxy-acetylene flame. The assembly is then heat-treated, which distorts it somewhat, necessitating regrinding the hold-down flange and the bottom of the barrel.

The inside of the cylinder barrel is now wet ground and then dry

ground with water passing through the jackets to keep it cool. The combustion chamber walls are not ground at all, as no running parts come into contact with them. Jackets are tested for leaks under 40 lb. water pressure.

213. Detail Specifications of Valves and Valve Gear. Valves are of the cone-seated poppet type and are mechanically operated by means of rocker arms driven by an overhead camshaft. The angle of the seat cones is 60 degrees with the center-line of the valve stem but in spite of the resulting thin edge of the valve head no trouble has been experienced from overheating and warping and it has not been found necessary to make the exhaust valves heavier due to the efficient cooling. Intake and exhaust valves are therefore interchangeable. The maximum lift of the exhaust valve is 7/16 in. and of the inlet 3/8 in.

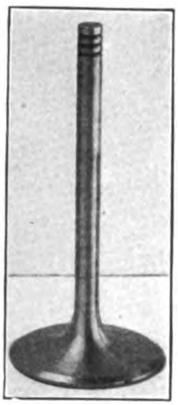

FIG. 345.—Liberty engine valve.

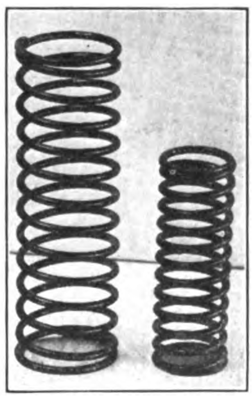

FIG. 346.—Liberty engine valve springs.

The valve head is of tungsten steel and is welded to a carbon-steel stem. Occasional trouble has been experienced from this construction due to failure of the weld, the loose head doing considerable damage to the piston. The extreme diameter of the head is 2¾ in. and the height of the valve, from center of lower face of head to top of stem, is 6 3/16 in. The weight is 9⅝ oz. Seats are hand reamed and the valves are provided with spiral steel springs of the following specifications.

TABLE XXV.—VALVE SPRING SPECIFICATIONS

Spring	No. of effective coils	Gage No.	Direction of helix	Tension when compressed to 2¼ in., lb.
Inside	12	11	Right	26½
Outside exhaust	10	9	Left	45
Outside inlet	12	11	Left	23½

This gives total tension of 71½ lb. to exhaust springs, and 50 lb. to the inlet. By using two springs per valve a greater compression is had, the outer fibers are subjected to less stress from distortion and a greater factor of safety is obtained as any one spring is strong enough to hold the valve against its seat.

The springs seat at the lower end on a cap which bears on the top of the valve cage, and are held at the upper end by a similar cap held in place by tapered washers which set in three grooves on the upper end of the stem, thus doing away with the necessity of using a key, and a key-

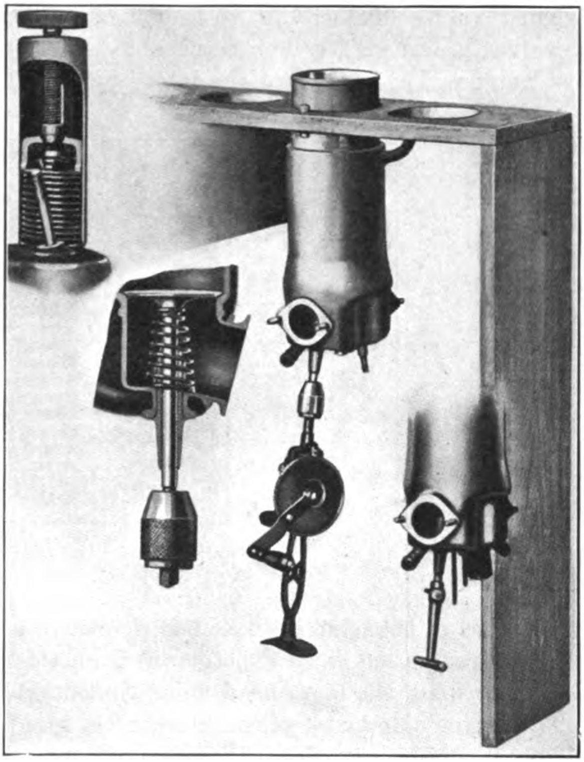

FIG. 347.—Perspective drawing of illustrating method of securing valves and valve spring.

way in the stem. The stem guides are hand reamed to the following clearances:

	Min. (inches)	Max. (inches)	Desired (inches)
Inlet..................................	0.002	0.00045	0.003
Exhaust..............................	0.004	0.0065	0.005

The rocker arms were machined from solid forgings on early engines, the journals being drilled for oil passages but this has been discontinued. The cam followers are ground to a cylindrical surface to give line contact

and should be free to revolve on their pins. In assembly this is assured by the use of a special tool which holds the legs at the proper distance apart, thus insuring correct clearance between them and the rollers.

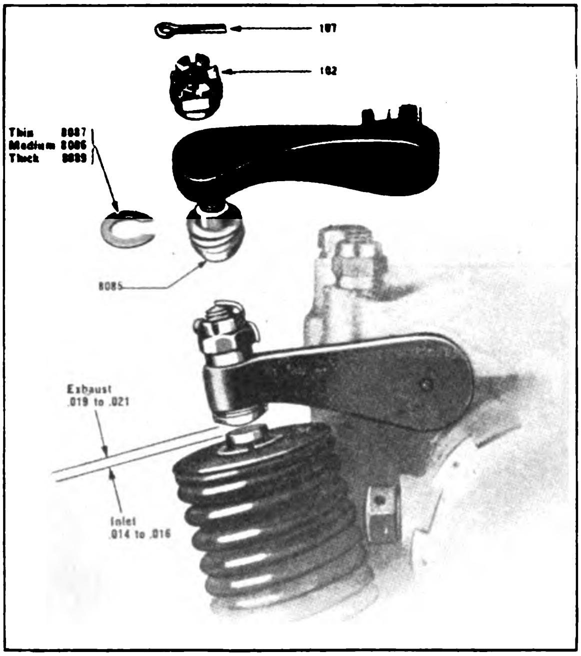

Fig. 348.—Rocker-arm tappet assembly.

The tappets have a cylindrical surface to give line contact and the heads are hardened. The part of the stem passing through the rocker arms is a square, fitting the square hole in the latter to prevent turning, and the

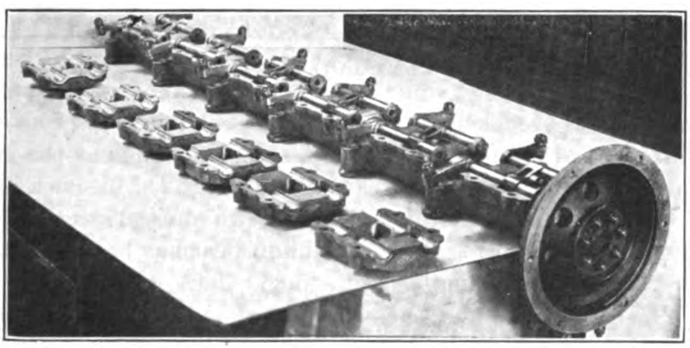

Fig. 349.—Top view of rocker-arm housing.

tappets are secured by castellated nut and cotter-pins. Clearances are secured by adjustment of tappet seats in the rocker arms removing or

adding special shims as necessary. Shims have an opening which allow them to be inserted across a flat part of the stem. They are held in position after they have slipped down below the flattened portion.

The cam followers do not ride directly over the camshaft center-line but are offset, thus affecting the angle between inlet and exhaust cams on the right and left camshafts since each follower engages its cam on the leading side in one bank and on the following side on the other. This sometimes results in excessive impact on exhaust side of right-hand shaft and consequent breakage of housing.

The inlet and exhaust rockers are interchangeable on opposite banks, but not in the same bank. However, they are marked for one bank only.

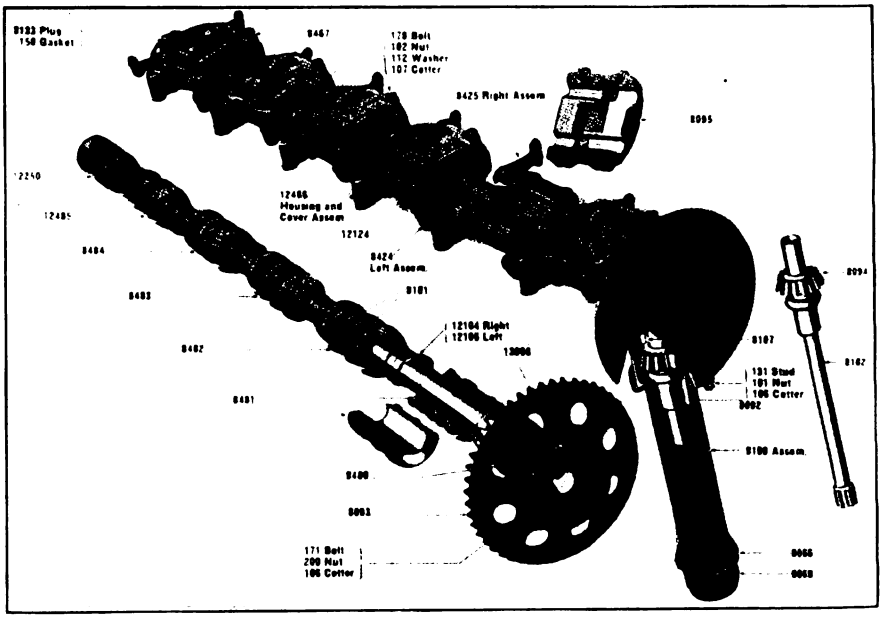

FIG. 350.—Camshaft-housing assembly.

The camshaft is of nickel-chrome steel of tubular sections 1 in. external and ¾ in. internal diameter, carrying a collar or flange at the gear end for the attachment of the drive gear, and another 2⅝ in. back of it, the forward bearing being carried between the two and carrying the thrust. The shaft rides in six other 3-in. aluminum bearings between each pair of cams, the journals being 5⅛ in. long. This construction gives a possible 2⅛-in. forward and backward movement of the shaft. Therefore, since all bearings are held securely in the housing by means of sets screws, it is only necessary to back out the screw in the forward bearing in order to slip out the shaft far enough to throw the drive gear out of mesh and make whatever timing adjustments may be necessary. The

annular rings in the outside of the bearing bushings which form the bearing surfaces in the housing, are cut through on either side near the bottom to allow the passage of oil through the housing toward the gear end and thus prevent flooding any part of the housing.

The shaft is drilled through from the propeller end to the gear end and the propeller end is plugged with a screw plug. Radial holes are drilled in each journal for the passage of oil but the cams are no longer drilled for this purpose.

The camshaft housing is a hollow aluminum casting provided with bosses for carrying the rocker-arm bearings. The camshaft bearings are separate and removable, as described above, and the rocker-arm bearings are carried as follows: the lower half in the bosses and the upper half in the removable cover plates. The inner corners of these bearings are cut away to give free access of oil to the rocker-arm bearings. The rocker-arm housing cover plates are attached to the main camshaft housing by four studs at the corners, three of which seat in the housing, while the fourth one continues through it and seats in the inlet valve cage on the cylinder thus securing the camshaft housing in place. The whole housing is held by the six studs described above, and also by six shorter studs on the opposite side.

In assembly the nuts are set up on the studs of No. 1 and 6 cylinders in order to get proper alignment. They are loosened and all nuts are set up beginning with those on the studs of No. 3 and 4 cylinders and working outward toward the ends in order to give even distribution of stress throughout the housing and prevent any buckling tendency in the center.

The front end of the housing protects the drive gear and forms a seat for the distributor head, a pin in the distributor-arm shaft fitting into an eccentric recess of the drive gear. The gear is attached to the supporting flange by means of seven equally spaced studs, thus allowing corrections of a fraction of a tooth in valve timing.

The rear end of the housing is covered by a plate which screws into it and carries the oil connections from the main oil lead to the rear bearing. A web at the front end of the housing serves to maintain a constant oil level in the housing.

Clearances	Min. (inches)	Max. (inches).
Diametrical shaft clearance	0.001	0.003
End play	0.002	0.004

It will be noted that this end play is regulated by the length of the forward bearing and is held within such narrow limits because of the bevel-gear drive.

Rocker levers	Min. (inches)	Max. (inches)	Desired (inches)
Diametrical	0.00025	0.00175	0.001
End play	0.0042	0.0122	0.0075

Arms should fall under their own weight when oiled.

Tappet gap	Min. (inches)	Max. (inches)	Desired (inches)
Exhaust valve	0.109	0.021	
Inlet	0.013	0.016	

214. Detail Specifications of Pistons and Wrist-pins. The pistons are lynite die castings of the solid-head type without cooling ribs. This design provides more metal at the head and upper skirt thus enlarging the heat path, lowering the temperature of the parts, equalizing expansion, and giving better running conditions.

The piston weighs 3 lb. 3 oz. A tolerance of ½ oz. is allowed all pistons in one bank. The diameter at the head cold is 4.96 in. and at the skirt cold 4.98 in. The length of skirt is 5 in.

The wall clearance is, minimum .018 in. and maximum .022 in. Pistons are selected for clearance and must not be more than .001 in. out-of-round.

The rings are of cast iron, three in number, concentric in type, the slot being cut on a 45-degree angle. The fit in the grooves should be such that, with an oil film established, they will remain in position when the piston is turned on its side but not so tight that they cannot be shaken about in the grooves.

The actual clearances are as follows:

	Min. (inches)	Max. (inches)	Desired (inches)
Fit in grooves	0.00125	0.003	0.002 to 0.003
Gap	0.021	0.041	

Light circular oil grooves, seven in number, are cut in the skirt of each piston to equalize the distribution of the oil around all parts of the pistons. They are spaced ½ in. apart with the lowest ¼ in. above the base of the skirt.

The piston-pin bosses are heavy and carried well down in the skirt after the Hall-Scott design in order to keep them away from the intense heat at the head. The distance from head to center of bearing is 3 in. The outer face of the boss is carried out to correspond to the rest of the skirt and corresponds with its curvature. Two grooves are milled in this face to receive the wristpin retainer.

The wristpin is of nickle-chrome steel of tubular section and is drilled radially for oil passages to the bearings. Its length is 4$^{19}/_{32}$ in., its outside diameter 1$^{7}/_{32}$ in., while the internal diameter is $^{27}/_{32}$ in., giving a wall thickness of $^{3}/_{16}$ in.

Wristpin clearances are as follows:

	Min. (inches)	Max. (inches)	Desired (inches)
Fit in rod	0.00125	0.00225	
Fit in piston	0.00025	0.00075	Selected for light-drive fit.

The pin is full floating, that is, it is free to turn with respect to both bearing bosses and the connecting rod bearing. It is prevented from slipping out and scoring the cylinder walls by lynite retainers which are

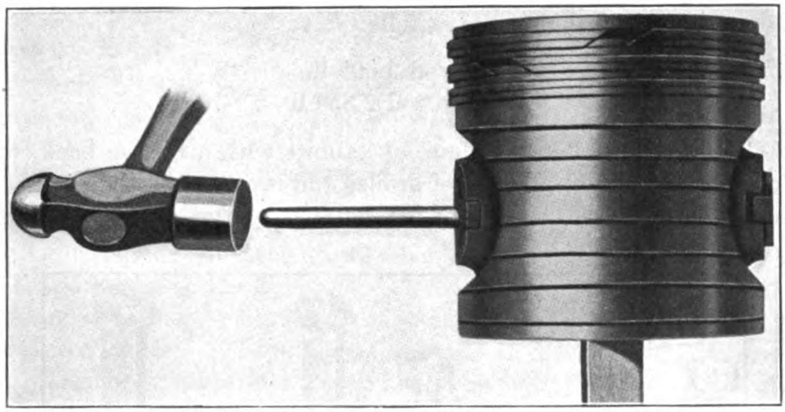

FIG. 351.—Removing piston-pin retainers.

held in the bosses by two lugs. The outer face of the retainers conforms in shape to the end of the boss and piston skirt. The retainer have holes through their centers into which a draw bar may be inserted in order to remove them. They should be a light-press fit in the bosses.

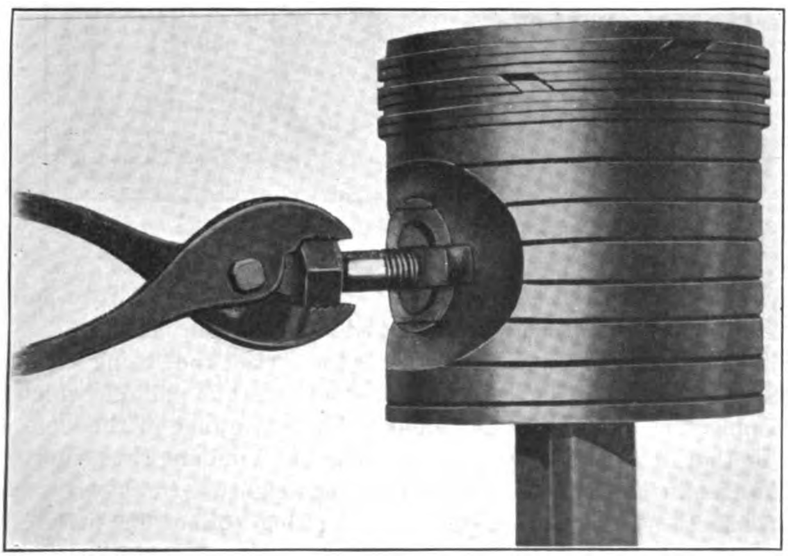

FIG. 352.—Removing piston-pin retainers.

In former models, brass plugs and spring wires were used but neither were successful because of high piston temperature.

215. Detail Specifications of Connecting Rods, and Bearings. The connecting rods are of the H-section, fork-and-plain rod type and are machined all over from steel forgings.

The length between centers in each case is 12 in. and the weights, without bearings bushings, are as follows:

Plain rod 2.609 lb.
Forked rod 2.859 lb.

The crankpin bearing is plain, of babbitt with a bronze back, while the outer bearing, also plain, is of bronze and is carried in the back of the forked-rod bearing. This use of bronze as a bearing surface is possible

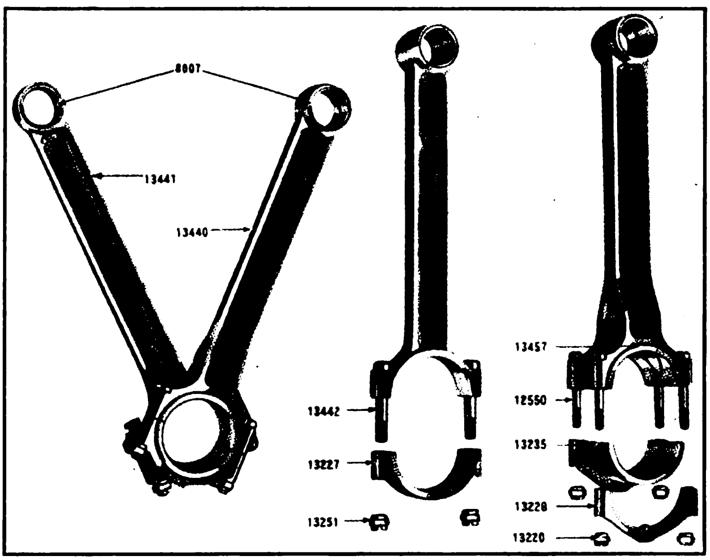

FIG. 353.—Connecting rods for Liberty engine.

since the action of the plain-rod big end is merely oscillatory and not rotating. This is also true of the forked-rod crankpin bearing.

The combined bearing is carried by the forked rod, being supported at the ends which affords a strong and secure method and one which aids in keeping the bearings in alignment. The advantage of this construction is that it permits opposite placing of cylinders thus shortering the crankshaft and crankcase and reducing weight.

It has the disadvantage that one bearing cannot be fitted independently of the other. The construction gives adequate bearing surface although there is a slight added difficulty in lubricating the bronze outer bearing. The wristpin bearing is of bronze, being subject only to oscillatory motion.

TABLE XXVI.—CONNECTING ROD CLEARANCES

Diametrical:

Bearing	Min. (inches)	Max. (inches
Forked rod (Ford Liberty)	0.0025	0.0045
Forked rod (all others)	0.003	0.004
Plain rod	0.005	0.0065
Piston pin (in rod)	0.00125	0.00225

End play	Min. (inches)	Max. (inches)
Forked rod	0.008	0.020
Plain rod	0.004	0.010

Between upper end and piston bosses 1/64

216. Detail Specifications of Crankshaft. The crankshaft is of the right-hand, bored type, the throws being arranged as follows: When No. 1 and 6 are vertically upward, looking from the gear end, No. 2 and 5 are at an angle of 120 degrees to the left, and No. 3 and 4 are 120 degrees to the right. The shaft is machined all over from nickel-chrome steel. The advantages of a bored shaft are lighter weight for a given

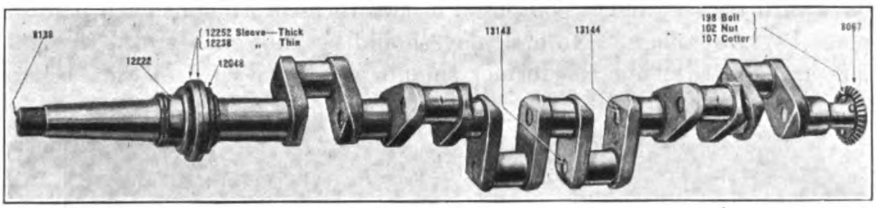

FIG. 354.—Liberty crankshaft.

strength; removal of poor interior metal; better opportunity for inspection.

The shaft, following modern practice, is carried in main bearings and one compound-thrust ball bearing at the propeller end.

The weight of the shaft without propeller hub is 97 lb. Its overall length is 4 ft. 9¾ in. The cheeks are 1 in. thick and 2⅝ in. wide. No. 1 to 6 main journals are 2⅝ in. in diameter and 2½ in. long. No. 7 journal has the same diameter but is 4⅞ in. long. The crankpin journals are 2⅜ in. in diameter and 2½ in. long. Tolerance of .001 in. is allowed in diameters but all bearings must be within .001 in. of each other.

The main bearings clearances are as follows:

	Min. (inches)	Max. (inches)
Diametrical clearance (Ford)	0.002	0.004
Diametrical clearance (all others)	0.0025	0.00325
Check clearance	0.0075	0.0775
End play (with thrust)	0.001	0.005

The hollow main and crankpin journals are closed with tapered steel plugs held in place by a through bolt and cottered castellated nut.

The propeller hub is machined from a drop forging and is patterned after the Hall-Scott design. The tapered hole is reamed to the proper gage to fit the tapered shaft, and the keyway cut. It is then heat-treated and shrunk to the shaft by heating to 220° F. Extreme care is taken to have flanges at right angles to shaft.

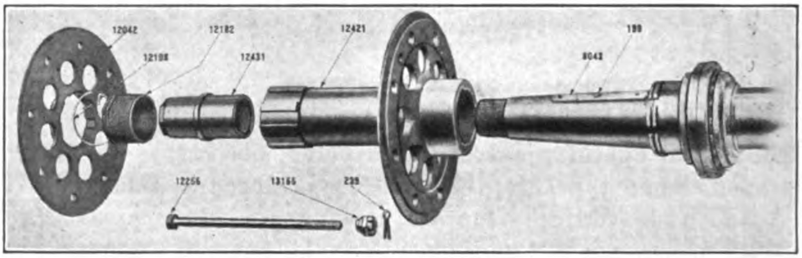

Fig. 355.—Liberty propeller hub and thrust bearing.

The thrust bearing is of the compound type taking both forward and backward thrusts and is composed of two races of 17 balls each held in place by two collars. No end play should be allowed between the collars and the case but the former should be free to turn in the case to

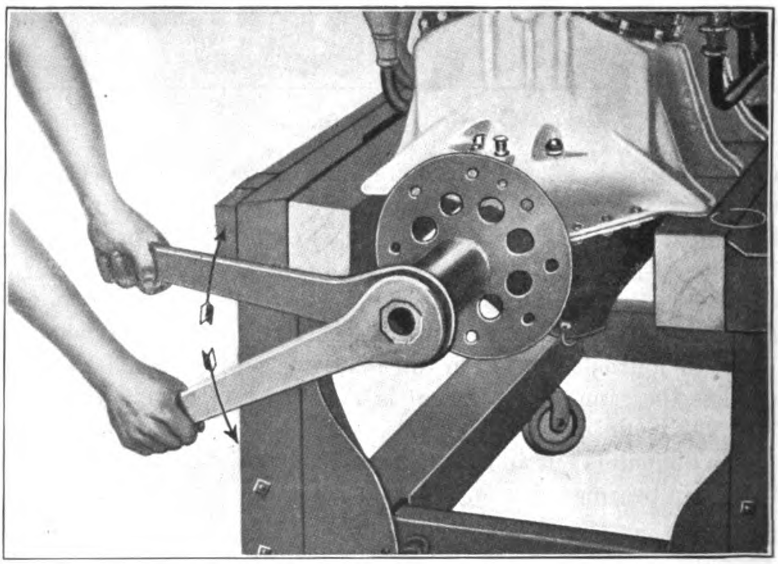

Fig. 356.—Removing propeller hub.

distribute wear more evenly. This fit may be obtained by selecting collars of varying thicknesses of which there are two standard thicknesses provided.

The bearing should be packed in grease at each reassembly and oiled

frequently through its individual oil cup, as it is not reached by the main system.

217. Detail Specifications of Crankcase, and Main Bearings. The crankcase is of the dry-sump type carrying the crankshaft bearings

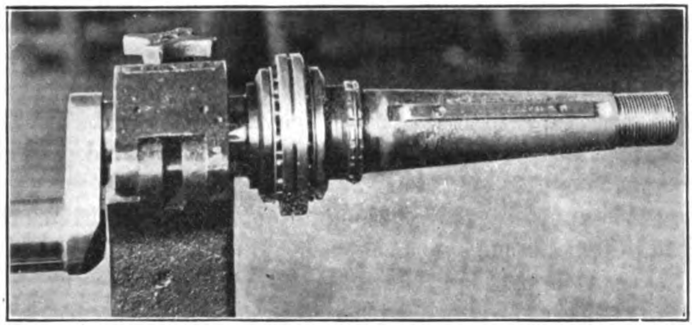

Fig. 357.—Component parts of thrust-bearing assembly.

directly in transverse webs in both the upper and lower sections of the case.

This type of bearing support gives increased rigidity and better facilities for fitting new bearings. It has this disadvantage, however,

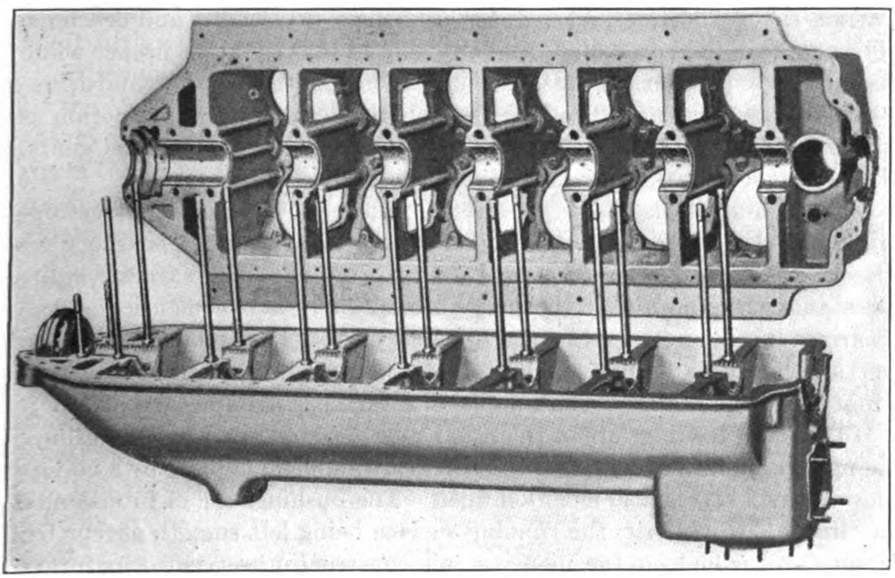

Fig. 358.—Crankshaft mounting in crankcase.

that it is impossible to adjust for wear in bearings since shims cannot be used.

The upper half of the case stripped weighs 76.125 lb.; the lower half, 52.5 lb.; the total crankcase 128.625 lb.

The two sections of the case are tied together by studs seated in the webs of the lower half and passing through the webs in the upper half and held by castellated nuts, cottered, and seating on the upper surface of the upper section of the case, and also by $\frac{3}{16}$ in. through-bolts in the flanges, whose nuts are secured by lock-washers. The case is supported in a flange on the upper section provided with pairs of supporting webs, one on either side of each hold-down bolt hole. Considerable trouble was experienced in the first crankcase by breakage of these webs and it was found necessary to make them heavier. The webs in the lower half of the case also cracked and were made heavier and provided with deeper fillets.

It is very important that the engine be supported on no other part of the case but the flange, since the case is not designed to carry the load in any other way and warping or possibly failure will result.

The crankcase is provided with two breather tubes carried fore and aft in the right-hand side of the upper section of the crankcase. Each tube is baffled to prevent excessive loss of oil and screened. The covers are held in a partly open position by special spring clips.

The forward part of the crankcase is divided from the remainder by a solid transverse web in the upper section and divided into the upper and lower compartments by a deck in the lower section. This space carries the gears, pump, generator, camshaft driveshafts and bearings. The gears are thus protected from oil vapor in the crankcase proper while an oil trap to prevent the passage of oil vapor from the camshaft and drive-shaft housings is carried on the horizontal deck. This construction is necessary because of the corrosive action of this vapor upon the gears. It also prevents breathing action through the camshaft housing.

The crankcase is provided with 7 transverse webs in each section, giving a stiff ribbed structure besides carrying the main bearings, as described above. Thus great strength is combined with extreme lightness and with the aid of the long through-bolts above mentioned, the bearings are securely tied to the cylinder deck. The webs in the lower section do not extend to the bottom of the case but are bridged across from the sides, leaving a continuous oil return passage fore and aft.

The main bearings are of the usual split type, one-half of the bushing being carried in each section of the crankcase and held in place by a hollow dowel which serves also as an oil duct. The bushings are of bronze and are lined with babbitt, the running surface being left smooth except for a short oil trough at the inlet, as this construction serves to maintain the oil film as desired, while oil grooves act merely as over-flow channels. With this type of case no shims can be used for adjustment of bearings and all bearing bushings must be carefully fitted and the edges filed to the level of the lapped surfaces of the case sections before the latter are bolted together or else the case will be sprung or warped.

In fitting a new set of main bearings the first operation is to fit the bushings in the webs as above. Then a Martell or other line reamer rigged up between centers and carefully centered in the bearings is used. The Martell reamer has seven sets of adjustable cutters which are set at shaft diameter plus the desired clearance and thus, with this reamer, all main bearings are reamed at one operation. They are then scraped to fit a mandrel whose diameter is journal diameter plus about .015 in., a 75 per cent. bearing surface being required. This mandrel should give a perfect fit in the bearing. The edges of the bearing bushings should be chamfered and care taken to see that a perfect fit is obtained in the bearings. The edges of the bearing bushings should also be chamfered and care taken to see that the journal fillet does not bear on the bushing. The reamer may be turned by hand or by power.

218. Detail Specifications of Camshaft-drive Gearing. This assembly consists of one single and two two-pieces nickel-chrome steel shafts carrying case-hardened bevel gears, similar to the Hispano-Suiza type.

The drive gearing is as follows: a 33-tooth bevel gear on the front end of the crankshaft drives a 22-tooth bevel gear on the lower end of a vertical shaft. A similar gear on the upper end of this shaft drives two like gears on the lower end of the lower sections of the camshaft driveshaft. These latter are in line with the cylinders and, hence, at an angle of 22½ degrees from the vertical. The generator driveshaft is in line with the vertical driveshaft with which it is spline connected.

The upper sections of these camshaft driveshafts are spline connected to the lower sections, the junction coming where the latter project from the cylinder deck; 16-tooth bevel pinions on the upper end of these shafts drive the 48-tooth gears on the front end of the camshafts. These latter mesh on the front side of the pinions so that the camshafts rotate in a clockwise direction.

The gear-train ratio is as follows:

$$\frac{\text{Driving gears}}{\text{Driven gears}} = \frac{33}{22} \times \frac{22}{22} \times \frac{16}{48} = \frac{1}{2}$$

Since speed is inversely proportional to the number of teeth the camshaft gear will turn at one-half crankshaft speed, which is the desired relation.

The valve timing of this engine is as follows:

Inlet opens	10° P.T.C.
Inlet closes	45° P.B.C.
Exhaust opens	46° B.B.C.
Exhaust closes	8° P.T.C.
Spark advance	30° B.T.C.
Spark retard	10° P.T.C.

The point of inlet opening, being that at which the cycle really begins,

is called the *neutral point*, and it will be noted that it is also the point of maximum spark retard which fact assists materially in the timing operation. In the first engines it was also the point of exhaust closing but this event has been advanced as above.

To time the valves in reassembly, proceed as follows:

1. Assemble 33-tooth gear in crankshaft so that marking is 12½ degrees to right of No. 1 throw, looking from gear end.
2. Place pistons No. 1L and 6L on top center.

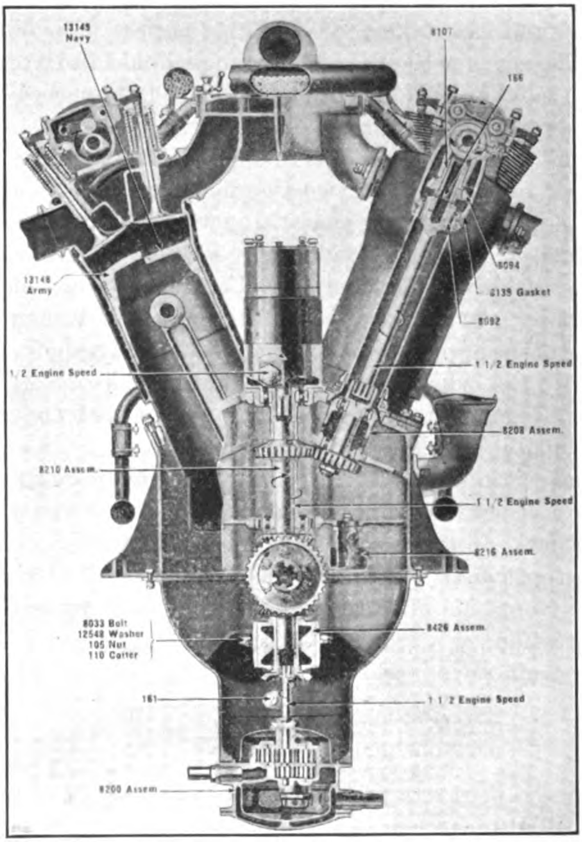

FIG. 359.—Transverse section camshaft-drive assembly.

(*a*) Put on timing disk and pointer gage.

(*b*) Insert plug gage in spark-plug hole.

(*c*) Turn engine so that piston is coming up on either side until crank is a few degrees before top center. Mark reading on gage and under pointer on disk.

(*d*) Continue in same direction until piston has gone up and down past mark on plug gage.

(*e*) Turn engine in opposite direction until mark on plug gage registers as in *c*. Mark under pointer on timing disk.

(*f*) Bisect subtended arc on disk and bring mark under pointer. Engine is on top center.

(*g*) Set disk so that mark T.C. of IL and 6L is under pointer.

(*h*) Set No. 1L on neutral point, that is mark "10—No. IL" on the timing disk, is set under the pointer. As an approximate method, turn the crankshaft until mark on its gear aligns with the center-line of the crankcase.

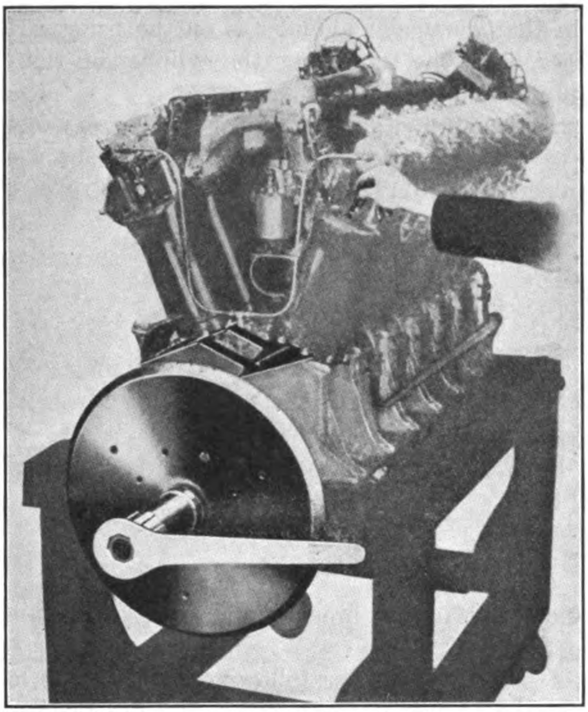

Fig. 360.—Using timing disk.

3. Mount generator-shaft assembly in any position, adjusting gear clearance by shims to give between .005 in. and .010 in. backlash.

4. Mount camshaft lower driveshaft, so that marks in spline are lined fore and aft.

5. Mount camshaft upper driveshaft assemblies so that marks on splines coincide with those on lower sections.

6. Mount camshaft assemblies so that marked teeth on gear and pinion are aligned. If these gears have not been disturbed in disassembly, check by this adjustment when assembling. If it is necessary to replace a camshaft or gear, proceed as follows:

Perform operations 1 to 5 as above and for the 6th operation mount camshaft set tappet gaps and rotate shaft in direction of rotation until inlet is about to open. Mesh camshaft gear and upper driveshaft pinion without disturbing setting of camshaft, by selecting proper position of gear on retaining studs. There are seven of these studs and with 48-teeth on the camshaft gear a variation of $\frac{1}{7}$ of a tooth or $2\frac{1}{7}$ degrees is obtained by moving the gear one stud.

7. If the tappet gaps have not been set, this should now be done and the gaps checked for each valve on each cylinder. This must be done accurately for each cylinder and the gap should be measured when the piston in that particular cylinder is on the firing stroke, which, it will be noticed, is at the time when the cylinder on the corresponding throw is around the neutral point.

An approximate method, depending for its accuracy upon the correctness of the cam and cam follower and faces, may be used as follows:

With crankshaft set at T.D.C. No. 1L, firing stroke, ckeck the following tappet clearances:

Left side		Right side	
Exhaust	Inlet	Inlet	Exhaust
5	4	6	6
3	2	5	4
1	1	3	2

With crankshaft set at T.D.C. No. 6L, firing stroke, check the following tappet clearances.

Left side		Right side	
Exhaust	Inlet	Inlet	Exhaust
6	6	4	5
4	5	2	3
2	3	1	1

8. Set and synchronized breakers gap and set advance at exactly 30 degrees.

In case of faulty timing the following adjustments may be made:

1. The camshaft gear has 48 teeth, hence, a variation of one tooth means a change of $\frac{360°}{48}$ or $7\frac{1}{2}$ degrees of camshaft rotation or, since the camshaft travels at half crankshaft speed, 15 degrees of crankshaft rotation. This correction is made directly, that is, in case of late timing, the shaft, with gear attached, is turned forward one or more teeth, as may be required.

2. The camshaft is attached to the camshaft flange by seven studs and cottered castellated nuts. By removing this gear and replacing it one stud hole in advance or retard of its original position, it is moved $\frac{48}{7} = 6\frac{6}{7}$ teeth. Then the shaft with gear attached, must be turned $\frac{1}{7}$ tooth or $\frac{15}{7}$ degrees in the same direction as the original gear change, to mesh with the driveshaft pinion. Therefore, this adjustment also is made di-

rectly, that is, in case of late valve timing, move the gear forward in the direction of rotation one or more stud holes, and then move shaft with gear attached, forward the added distance necessary to mesh.

Always check timing by rotating the engine forward in the gears.

219. Detail Specifications of Attached Accessories. *Ignition System.* The first and second are not present in the Liberty ignition outfit. The third system or the generator is not in conjunction with a battery for the following reasons.

It gives constant voltage and hence, uniform intensity of spark at all times and under all conditions of operation.

It is the simplest system on the basis of adjustment and maintenance, since with the unconventional V-angle of 45 degrees it would be necessary

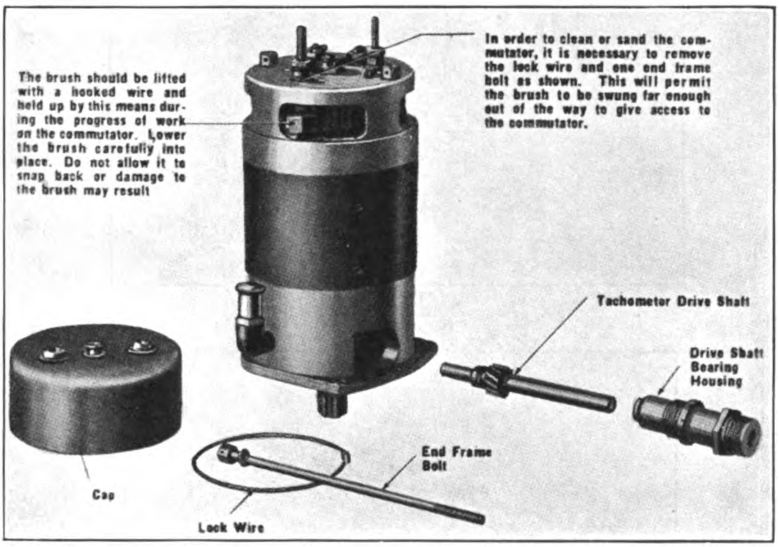

Fig. 361.—Liberty generator.

to use four magnetos which would complicate the process of timing as synchronization of all would be necessary.

The generator, manufactured by Delco, is of the shunt type with wave-wound armature. It is carried vertically on the crankcase deck, at the gear end and driven directly from the vertical driveshaft, running at 1½ engine speed.

It should be remembered that at engine speeds of 650 r.p.m. and less, generator speed of 975 r.p.m. and less, the generator voltage will fall below that of the battery, causing flow of current from battery to generator when running on double ignition. Hence it is absolutely necessary to run on battery alone under these conditions.

Carburetors. This engine uses Zenith Model U. S. 52 Duplex car-

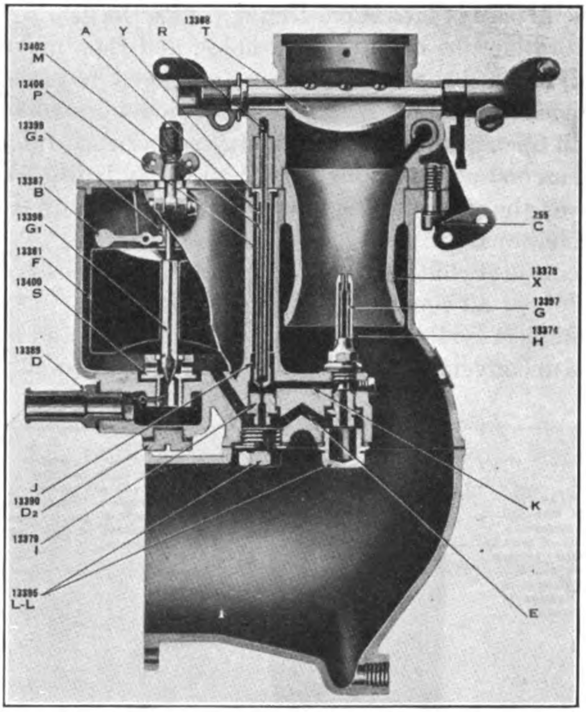

Fig. 362.—Zenith carburetor section.

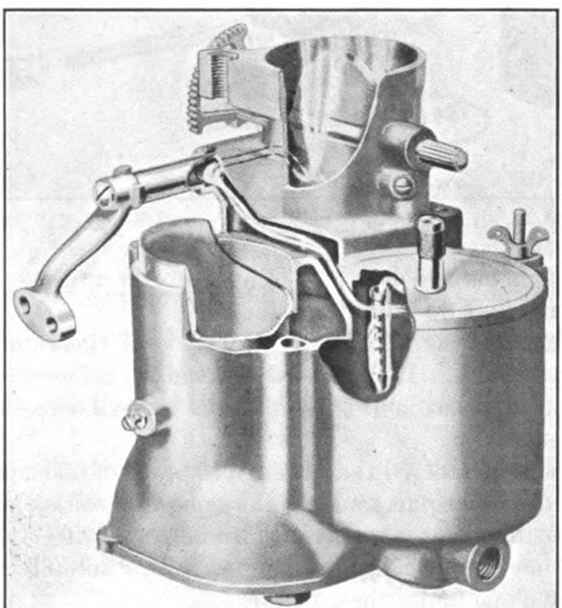

Fig. 363.—Zenith carburetor perspective.

buretors. Two assemblies are used, each consisting of two separate barrels with individual jets and throttles, each barrel supplying three cylinders in one bank. This arrangement gives the best possible distribution of the demand upon the fuel supply system, no one barrel being called upon twice to supply a charge until all the others have been utilized, and, by referring to the firing order it is seen that this demand is made at equal intervals.

The carburetors are carried in the vee between the cylinder banks, being held against the under side of the intake manifold by long through

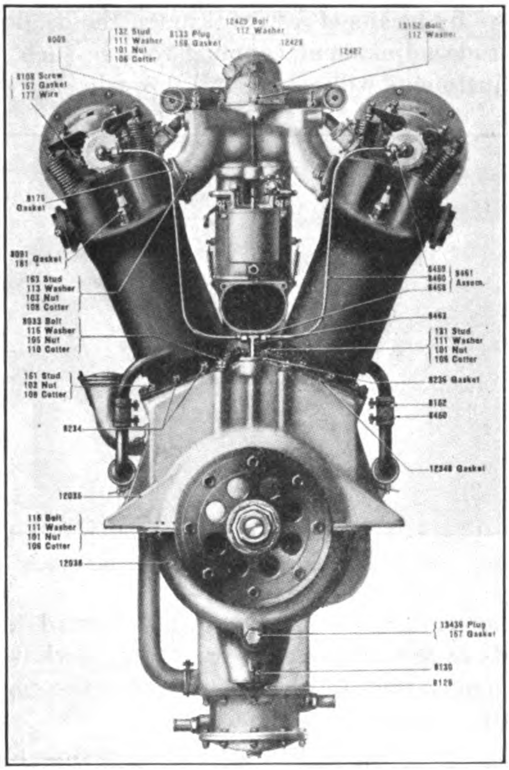

Fig. 364.—Carburetor mounting in Liberty.

bolts, which pass through the latter, one serving also to hold the water-outlet header connection in place. The manifolds are four in number, one for each three cylinders and each supplied from one carburetor barrel. The mixture enters directly from the barrel in the center of the under side of the manifold casting and is carried by its momentum up against the underside of the roof, spreading out under it and passing around the ends of a baffle plate in front of the inlet to the middle one of the three cylinders, flowing in equal proportions to all. A water jacket over

the top of the gas passages effectually heats the mixture, since the mixture comes in contact with the roof over which the hot water passes.

It is very important that the four butterfly throttle valves be carefully synchronized in order to give a mixture of equal proportions to all cylinders. This is done as follows:

Screw out the throttle stop screw on each carburetor until it clears the gear sector when the throttles are entirely closed. Slack off the adjusting screws until the lever clears each one of them by approximately $\frac{1}{16}$ in. Now entirely close the throttles, and holding them firmly, screw up the adjusting screws until they just touch each side of the lever, locking the screws by means of a wire through the head of each. Connect up the altitude adjustment coupling rods in such a manner that both altitude adjustments will get the full throw in each direction.

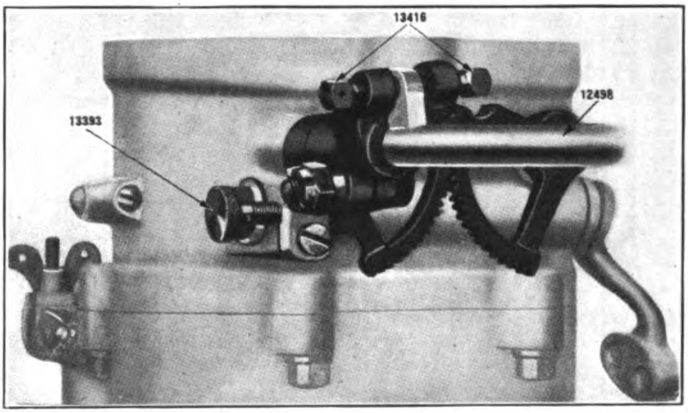

FIG. 365.—Carburetor synchronizing adjustment.

Ordinarily the air inlets would be turned toward the propeller to get the full benefit of the air stream, but in Navy work it is found necessary to turn the rear inlet toward the gear end of the engine in order to protect it from the salt spray.

In order to prevent the possibility of fire, the individual air intakes have been removed from the carburetors in the later engines and a single long intake *A* is provided and held in place by spring bales *C*. This is a T-shaped casting, the middle connection receiving a large single intake pipe *B* extending up through the vee of the engine and out through the bonnet, its upper end being cut off at an angle of 25 degrees. A dowel *D* engages a slot in this intake pipe *B* and prevents it from turning, and a clamp band *EE* anchors the pipe *B* to suitable cap screws already existing in the intake headers. This is shown in the accompanying figure, as well as the bend in the water outlet pipe made necessary by installation of pipe *B*. The intake header *A* is provided with nipples *GG* at

each end so that overflow pipes may be attached and carried outside the fuselage or boat body. This provides for the complete draining away of all stray gasoline whether the plane be diving, climbing or flying level.

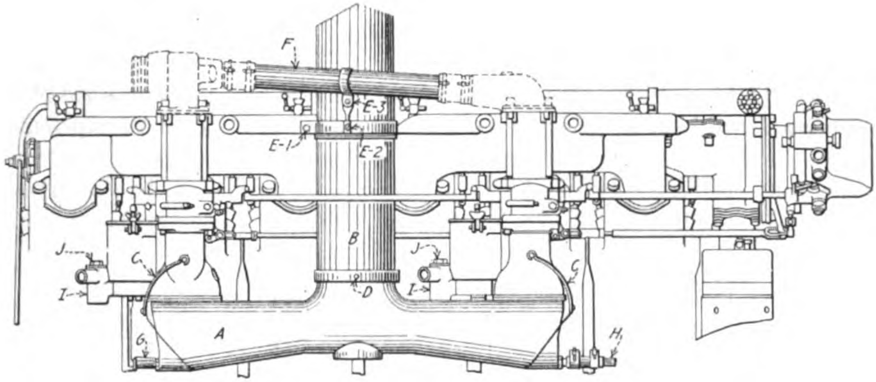

Fig. 366.—Longitudinal elevation showing revised carburetor arrangement.

As an additional precaution, screens are placed at the carburetor and beyond all hose connections in order to prevent passage of rubber particles to the carburetor which might stop up the jets. The screen

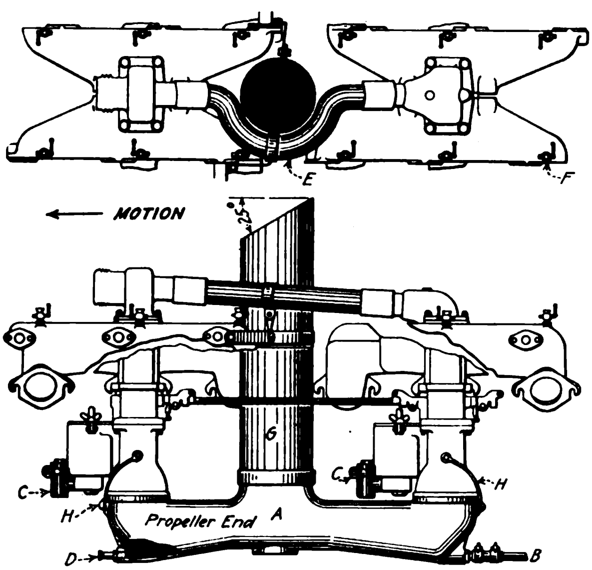

Fig. 367.—Carburetor air intake.

is carried in a small aluminum casting *I* which screws into the carburetor inlet connection. It carries a nipple to receive the gasoline hose connection and the screen is easily removable by taking off the nut *J*.

In Navy practice the following dimensions should be used:

Check	No. 31
Jet	No. 145 or No. 155
Compensator	No. 70

The float-valve mechanism is so arranged that the gasoline level will be maintained at a point 1/8 in. below the top of the main and cap jets.

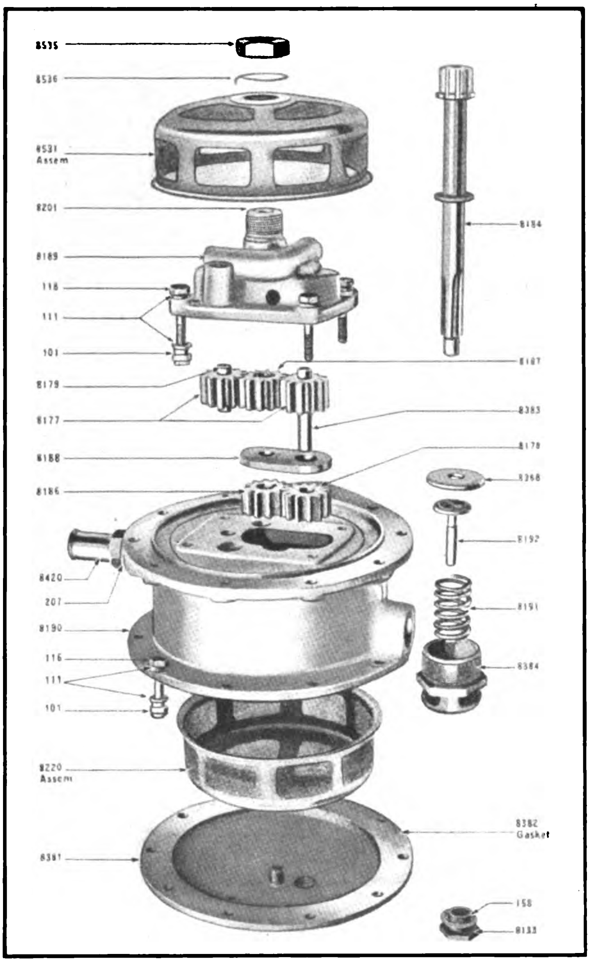

FIG. 368.—Liberty engine pump components.

If the mechanism should become deranged so that it does not maintain this level it may be corrected by moving the level-retaining collar toward the point of the float needle to raise the level, and away from the point to lower it. This collar is pressed on the stem and soldered.

Oil Pump. The oil pump is of the gear type, five gears being arranged in two decks and it is carried on the under side of the gear end of the crankcase directly below the gear chambers, being attached by ten 3/16-in. studs provided with cottered castellated nuts. Both sets of gears are driven by a single vertical shaft, spline connected to the lower vertical driveshaft.

Three gears in the upper deck drain the oil from the engine and deliver it to the storage tanks, the left-hand gear drawing from the forward sediment sump, to which the oil from the main and crankpin bearings and cylinder walls drains, and the right-hand gear drawing from the front sump directly above it, to which the oil from the cam-

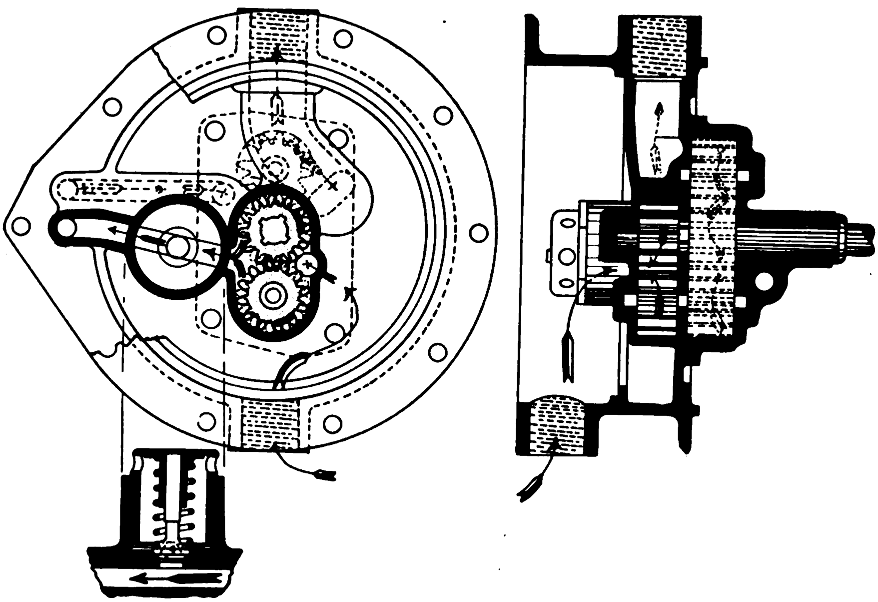

FIG. 369.—Liberty oil pump gearing.

shaft housing drains through the gear chamber. These two lines have a common outlet on the left-hand side of the pump housing.

Two gears in the lower deck draw oil from the storage tanks and pump it past the pressure release valve to the main oil lead.

Water Pump. The water pump is of the centrifugal type, carried at the front end of the crankcase and driven by bevel gearing from the lower gear on the vertical driveshaft and running at one and one-half times engine speed. It has a capacity of 100 gal. per min. with a free outlet at 1,700 r.p.m. of the engine. The shaft is carried in a plain bearing provided with a stuffing box and driven through a spring connection from a bevel driveshaft carried in a plain bearing, as above and one ball-thrust bearing. The end play in the impeller shaft should not be

over .010 in. while that in the bevel driveshaft should be from .005 to .008 in. The ball-bearing end play should be .005 in. while the clearance should be from .0015 to .0025 in.

The impeller is of bronze, keyed to the shaft and held in place by a cottered castellated nut.

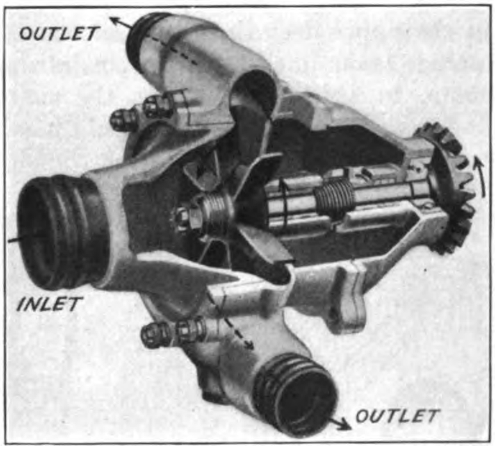

FIG. 370.—Liberty engine water-pump assembly.

The 2-in. inlet is carried in the front cover plate, the water entering axially and leaving tangentially through two 2-in. outlets, each feeding one of the 2-cylinder inlet headers.

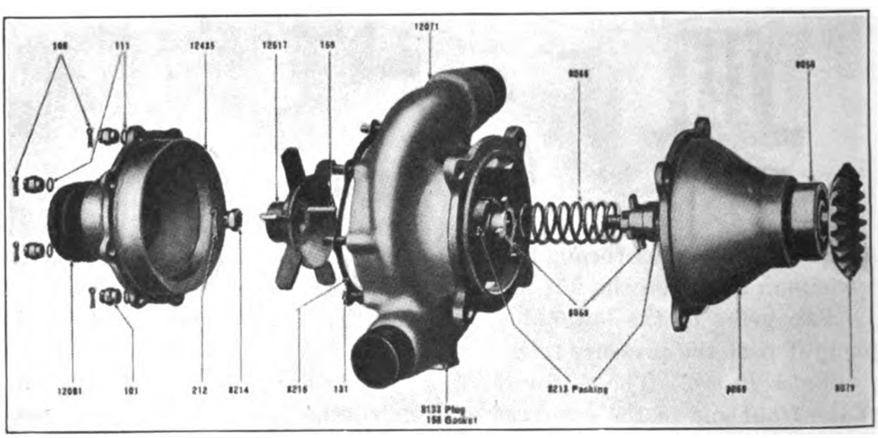

FIG. 371.—Liberty engine water-pump components.

The housing proper is held to the crankcase by four studs, all provided with cottered castellated nuts.

220. Detail Specifications of Detached Accessories. *Radiator.* The radiator is of the honeycomb type, carried in two different positions: in

front of the engine on the HS-1L and HS-2L boats, and in the center section of the upper wing, conforming to its contour, in the H12 and H16 boats.

The front type, used with the pusher engines, furnishes 350 sq. ft. of cooling surface, which, figured on the standard allowance of ap-

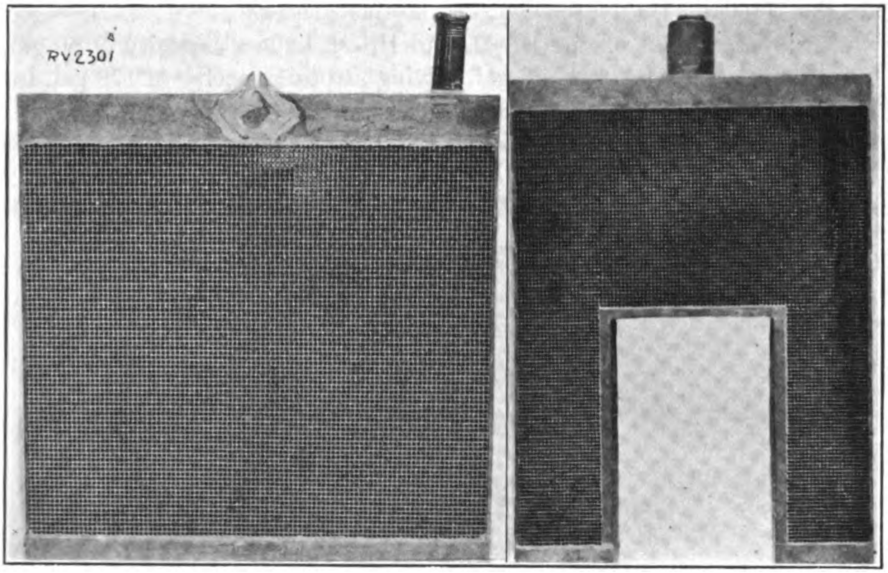

Fig. 372.—Radiators for HS-1L and HS-2L boats.

proximately 1 sq. ft. of cooling surface per b.hp. at 50 miles per hour, gives for the 385 hp. rating at speeds of 60 miles per hour at sea level, $1.08 \times 385 \times {}^{50}\!/_{60} = 345$ sq. ft. As this is below the normal average flying speed of these boats, the allowance is considered sufficient.

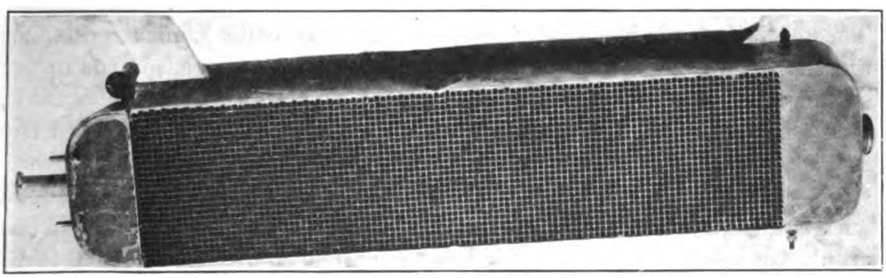

Fig. 373.—Radiators for H12 and H16 boats.

One radiator is used per engine and is seated in a frame to which it is held by through-bolts and which in turn is bolted to the engine bed, while a similar frame bolted to plane structure at each end holds it at the top.

The wing type, being in the path of maximum air velocity, requires less cooling surface and is the more efficient of the two, but no figures are yet obtainable upon performance.

Gasoline Tanks. On the H-boats, the main gasoline storage is in the boat bottom, carried in three vertical cylindrical or two vertical cylindrical tanks in the HS-1L and HS-2L and in one or two horizontal tanks in the H16 and H12.

The main tanks on the HS-1L and HS-2L have a capacity of 50 gal. each and the gravity tank 28 gal., giving a total capacity of 178 gal. for the installation, a quantity sufficient for about 4½ hr. of flight.

The three tanks on the H12 and H16 have a combined capacity of 385 gal., which, with the 56 gal. in the two gravity tanks, gives a total capacity of 441 gal. for the entire installation, sufficient for about 5½ hr. of flight.

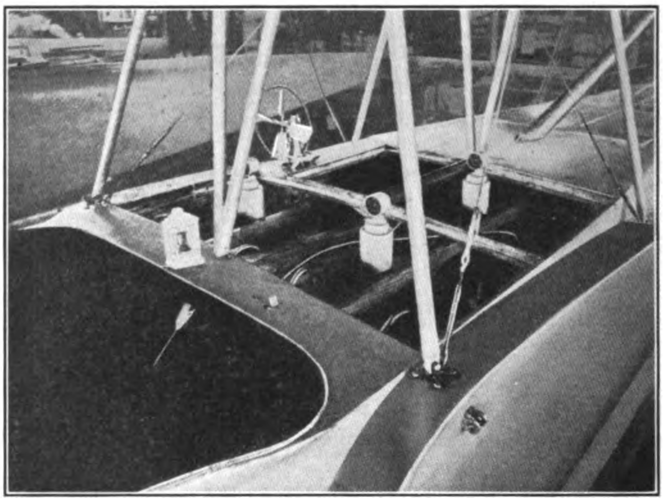

Fig. 374.—Fuel storage system, HS-1L and HS-2L boats.

The gravity tank in the HS-1L is cylindrical, with conical ends, an attempt at stream lining. On the HS-2L for the same reason the upper surface is curved, coming down sharply at both ends. An auxiliary tank, sometimes used on the HS-2L, fits into the vee of the engine behind the rear carburetor and holds about 1 gal.

Oil Tanks. Oil tanks are of brass, two in number, of cylindrical section with conical ends. They are carried in the fuselage, on each side of the crankcase, above the supporting flange. Their combined capacity is 13 gal. Their position, above the pump level, insures positive pump action at all times. The tanks are connected in parallel, the inlet from the return pump being midway between them on a cross connection and carries the oil temperature gage connection. The exposed position of the tanks and pipe connections aids greatly in cooling the oil, and no other

means has been found necessary to keep the temperature within reasonable bounds under normal conditions.

Fuel Supply Pump. The fuel supply pump is a wind-driven 2-gear pump with a 4-blade fan, the pitch of whose blades may be changed at will to obtain the proper speed and rate of delivery to the gravity tank. In some extreme cases it is necessary to cut out two of the blades in order to keep the pump speed within the desired limits. The shaft bearings should be packed in grease.

(*a*) *Tachometer.* The function of the tachometer is to measure the speed of revolution of the engine shaft. It is necessary to know this before starting from the ground to be sure that the engine is running at a speed

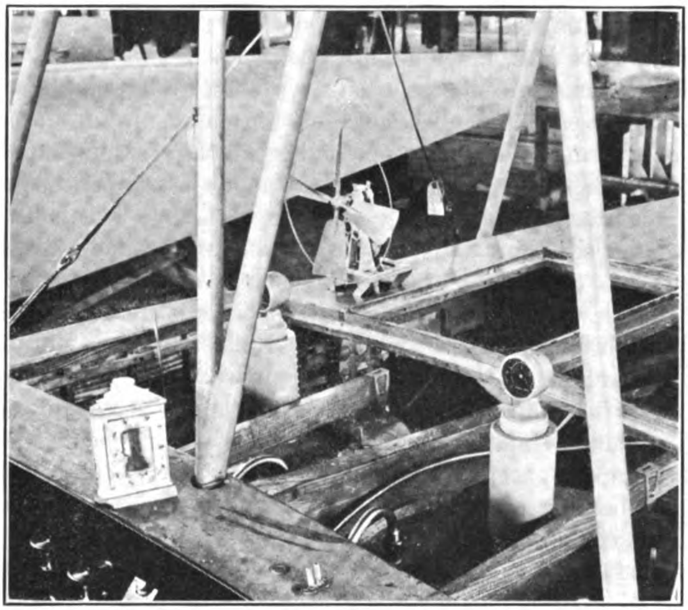

FIG. 377.—Wind-driven fuel supply pump.

safe for flying. When in the air the pilot can tell by the feel of the ship whether the engine speed is sufficient, without much difficulty, but if it is not sufficient before leaving the ground or water he is likely to find it impossible to get off in time to avoid an accident. Hence this instrument is necessary to warn against trouble. It is also useful in the air as an indication of engine trouble that might cause slowing down of speed and give a warning of possible engine failure. The third use for it is to enable the pilot to set the throttle readily to whatever speed he knows to be desirable, from the point of view of engine economy in level flying, or whatever condition of flying he may desire.

One of the principal types of tachometer depends upon the centrifugal

action on a weight attached to a shaft in the instrument, rotated through a flexible transmission from the engine. This centrifugal action is not proportional to the speed but increases with an increase of speed and if the parts concerned are allowed to move against a spring, it can be usek to produce motion of the indicating hand. The Johns-Manville tachometer is an example of this type.

The chronometric type is a combination of an actual revolution counter and a clock which interrupts the action of the counter at definite intervals, usually seconds. The reading of the hand is dependent on the number of revolutions made by the counter during the last interval between interruptions. Examples of this type are the Van Sicklen and the Tel, made in this country by the National Cash Register Company. This type, although more complicated than the centrifugal type, can be made to work with much greater accuracy.

In the Johns-Manville, as used at present, the weights moved by centrifugal force are three pieces of brass set equidistant around the shaft and held by arms attached on one end to a collar fastened to the shaft and on the other end to a sliding collar, as in the ordinary Watt steam-engine governor. Opposing the centrifugal action is a helical spring coiled around the shaft and pushing the movable collar away from the fixed one. As the motion of the collar increases faster than the speed of the shaft, a lever at approximately 45 degrees is used to transmit the motion to the hand of the instrument. If this is properly adjusted the motion of the hand of the instrument is approximately in proportion to the speed of the shaft. The lever is provided with a system for adjustment by a small screw. This adjustment is very delicate and should not be attempted except by a skilled instrument repairer. Proper and permanent bearing of lever on collar is difficult to get as the bearing point is subject to wear.

This instrument is quite rugged and should rarely require any repair. The most common breakage in practice is that of the flexible shaft transmitting power from the engine and as a rule this requires a shaft. If the instrument fails from any other cause, the cover and dial should be taken off and the instrument carefully inspected for loose parts or breakage. If the repair work cannot be done with tools at hand, the instrument should be sent to an expert repair man.

The chief faults are friction, and the design should reduce the number of friction points as much as possible; lost motion, lag and lack of balance, giving error, when tipped or when subject to side accelerations.

The construction of the chronometric type differs in detail between different makes and is much more complicated than the centrifugal type. On account of its complexity it is not suitable for description in brief notes or without a diagram. To understand it one should remove the hand and dial and operate the instrument slowly by hand and observe

the motion of the different parts. If the instrument is broken and requires inspection, obtain another instrument which is not broken and inspect that first, being careful to understand the working of every part before attempting to do anything with the broken one.

In case of breakage, the best advice that can be given is, as in the case of the centrifugal type, to look first for breakage of the flexible shaft and then inside the case. Send the instrument to a repair shop unless the cause of the damage is fairly obvious and easy to repair.

The best known example of the magnetic tachometer is the Stewart-Warner, used mostly in automobile speedometers. Its action depends on the fact that if a magnet rotates near a copper disk it drags the disk with a force proportional to the speed of rotation. It is subject to serious errors due to changes in strength of the magnet with vibration, changes in the air space between the magnet and disk, with temperature and other causes. Reports from abroad upon this type are unsatisfactory and it has not stood the tests well.

The air-drag type contains two disks, facing each other, one rotating at the speed of the shaft and the other allowed to run until stopped by a spring. The air friction between the disks produces a couple tending to make the stationary disk follow the moving one. This instrument is subject to errors due to changes of air density with altitude and consequent changes of drag. It is not used at present.

The air-pump type depends on the reaction of a stream of air pumped by a rotary pump connected to the engine and allowed to work on a spring valve whose degree of opening indicates the speed. Changes of air density make it also unsatisfactory in this country. Hence, though there are a great many of these instruments on early training planes, no more are being purchased.

(*b*) *Pressure Gages.* The purpose of the oil pressure gages is to give a warning to the aviator in case the pressure in the oil system is not at the proper value. A drop of pressure might occur if the oil system leaks or if the oil is for any reason exhausted, whereas a rise of pressure might be caused by any part of the system being stopped up. The pilot should therefore look at the oil pressure gage once in a while and consider any serious variation of pressure from the proper value as a warning of danger.

In some engines, such as the Hispano-Suiza, where the gasoline tank is under pressure, it is necessary to use a gage to register the pressure of the air. A great excess of pressure, although unlikely, might conceivably burst the tank or connections, but a drop of pressure due to any leak in the system is likely to cause the engine to stop and should therefore be guarded against. The type of gasoline feed is not fixed by the engine but by other considerations.

The oil and air gages are both operated by the Bourdon tube principle, similar to that used in a steam gage. The Bourdon tube is a springy

tube of flattened cross-section, bent in a curve, usually an arc of about 200 degrees. It is closed at one end and supported only from the other end which communicates with the pressure system. Under pressure the tube straightens out a little, the amount of straightening depending upon its springiness. The resulting motion of the closed end is used to measure the pressure.

In the oil and air gages, unlike the radiator thermometer but like an ordinary steam gage, the tube is bent through an arc of only about 200 degrees. The motion of the end of this tube is then magnified by a lever and gears to operate the hand. Both gages are identical in type and differ only in the details of size of levers and stiffness of the Bourdon spring.

This instrument is not subject to many possibilities of breakage, but if disabled can be taken apart and inspected and faults found very easily. It should be easy under most circumstances to remedy any breakage in the field.

(c) *Radiator Thermometers.* The purpose of the radiator thermometer is to indicate the temperature of the water. It is necessary to know this before running the engine at full speed, to be sure that the engine is warm enough so that the water is flowing properly and this is especially necessary before starting from the ground to avoid danger of having the engine miss and stop before a sufficient altitude is attained. While in the air the radiator thermometer will also serve as a warning if one or two cylinders are missing because the temperature of the water will be lower. Unless the engine is being run at constant speed, the indications on this point are liable to error and great dependence cannot be placed in them. As a rule an engine should run at a temperature between 40° and 86° F. below boiling. That is to say, near the ground it should be in the neighborhood of 176° F. and at 20,000 feet, where the boiling point of water is only 176° F., the temperature should be correspondingly lower. If the temperature is not within this range there is something wrong, and if it runs much higher, especially up to the boiling point, it is a definite sign that something is radically wrong with the engine, and a warning that a landing should be made as soon as possible.

The theory of the thermometers now in production depends upon the fact that a liquid in a closed vessel will evaporate until the pressure of the vapor reaches a value which is determined absolutely by the temperature of the liquid. A bulb filled with liquid is introduced into the radiator of the engine and the pressure within the bulb will be determined by the temperature of the radiator water. This pressure is transmitted from the bulb to a pressure gage on the dashboard of the airplane by a small tube filled either with the same liquid as the bulb, or in the French instruments, with glycerine which is not so volatile, the pressure gage on the dashboard being graduated in terms of the temperature of the bulb

rather than in actual pressure. Thermometers of this type are being made by the National Gage and Equipment Co.

The pressure referred to in the last paragraph is actual pressure or force per unit area exerted by the liquid on the inside of the bulb or pressure gage. The reading of the gage is determined actually by the difference between this pressure and the pressure of the air on the outside. Consequently, if the pressure of the air is changed by increasing altitude, the pressure difference is changed and the reading of the instrument is changed. This means that if the bulb is graduated to read correctly at sea level, the readings will be somewhat increased at high altitudes. In practice the liquid used is usually ethyl ether. Methyl-chloride thermometers are just being started in production, whose pressure at the temperatures ordinarily used is from 15 to 20 atmospheres. Consequently, the correction involved in the loss of half an atmosphere is never more than a degree or two. In the older instruments, which used the less volatile liquid, ether, the correction is larger. Where accurate work is required, this correction should be obtained from the makers of the instrument, but for ordinary purposes it may be neglected. The ether-filled thermometers may be indentified by the fact that the boiling point of 20,000 feet is put at 185° F. on the scale.

In the construction of the vapor-pressure type, the metal bulb is inserted in the pipe leading to the radiator through a screw plug which may readily be removed and is connected to the pressure gage by a long, somewhat flexible tube. In mounting the instrument great care should be taken that this tube is not sharply bent and especially that it is not broken or made leaky, as any leak will at once damage the instrument entirely. The pressure gage is of the Bourdon spring-tube type. It is essential that the bulb should contain enough liquid so that some always remains in it even when tube and gage are filled, but not so much that the bulb is more than full at low temperatures.

The principal type of accident which can happen to this instrument is that of being made leaky by having a sharp bend put in the small tube during mounting or through excessive vibration. If this happens the instrument is impossible to repair in the field and should be sent back to the factory. Minor troubles in the pressure gage might be repaired in the field.

A type of thermometer made by the Boyce Motometer Co., of which many are in use, is the liquid-filled type. This looks like the vapor-pressure type but is filled completely with liquid under a considerable pressure, and the liquid is not volatile enough to vaporize at the pressure used. The liquid used by the Boyce Co. is alcohol. The Bourdon tube is operated in this case by the expansion of the liquid as the bulb is warmed. Pressure at 212° F. is about 800 lb. per sq. in. In this type also there is a correction for the change of air pressure on the outside of the gage with

change of altitude, amounting to a degree of two in extreme cases. In addition there is an error due to the expansion of the liquid in the capillary tube connecting the bulb with the pressure gage. There is also a possibility of a permanent error if the column of the capillary is changed by repeated bending in the process of mounting the instrument. On the Boyce instrument the boiling point at 20,000 ft. is marked at 176° F., whereas the true boiling point there is 830° C. The capillary and pressure errors together are assumed to be 5°.

The liquid-filled type is like the other type, except that as the Boyce Co. makes it, the Bourdon tube is a long strip coiled in 20 to 25 turns, so that the motion of the end is large enough to need no further magnification in connecting to the hand and the capillary tube is of a special construction designed for the smallest cross-section that can be made without danger of plugging.

(*d*) *Gasoline Level Gages.* The purpose of the gasoline level gage is obviously to tell the pilot how much fuel he has left and therefore how far he can go without landing. Unfortunately there is no satisfactory gasoline gage in use at present, although the several unsatisfactory ones are in use and new ones are being tried.

The pressure type of gage in use, though abandoned for use on fighting planes, is dependent on the difference of pressure between the top and bottom of the gasoline tank, due to the weight of gasoline. The pressure is transmitted from each place by a small tube and the difference between the two pressures measured by a gage on the dashboard. This much is, of course, similar to the Bourdon tube used in the oil and air gages. The defect in this system lies in the fact that if a bullet breaks one of the pressure tubes, the gasoline can escape and the system is therefore more vulnerable than without such a gage.

Another type depends on a float supported by the gasoline which is kept in a vertical line by one or two upright bars fixed inside the tank. This float contains a hole of elongated cross-section through which runs a twisted strip of metal. As the float moves up and down and is prevented from turning by the bars, the twisted strip is forced to turn and the motion of the twisted strip is transmitted to the gage.

Another type is dependent on the action of a float attached to a lever, pivoted at the side of or top of the gasoline tank, and transmitting its motion to the hand of a dial.

In the twisted-strip type the bars supporting the float must be held from a cap in the top of the tank and the twisted strip must stick out through this cap. This makes it simpler to place the dial on the top of the cap, though it is possible to transmit the motion through flexible shafts or rods to a dial on the dashboard. The float is usually a hollow brass box, but sometimes is made of shellacked cork.

These instruments rarely work for any great length of time without

getting stuck, usually because a slight bend in either the rods or the twisted strip will cause the instrument to jar and because lubrication is impossible in the presence of gasoline. To repair them it is necessary to remove the instrument from the tank and locate the jamming position and straighten it if possible.

Battery. A four-cell storage battery, either Willard or Exide special models, with a capacity of 11.2 amp. at a discharge rate of 1.4 amp. or 9 amp.-hr. at a rate of 3 amp., weighs 10.5 lb. complete and is carried at any convenient point on the engine support.

Starters. There are two starters used on this engine, the Perfect and the Christensen.

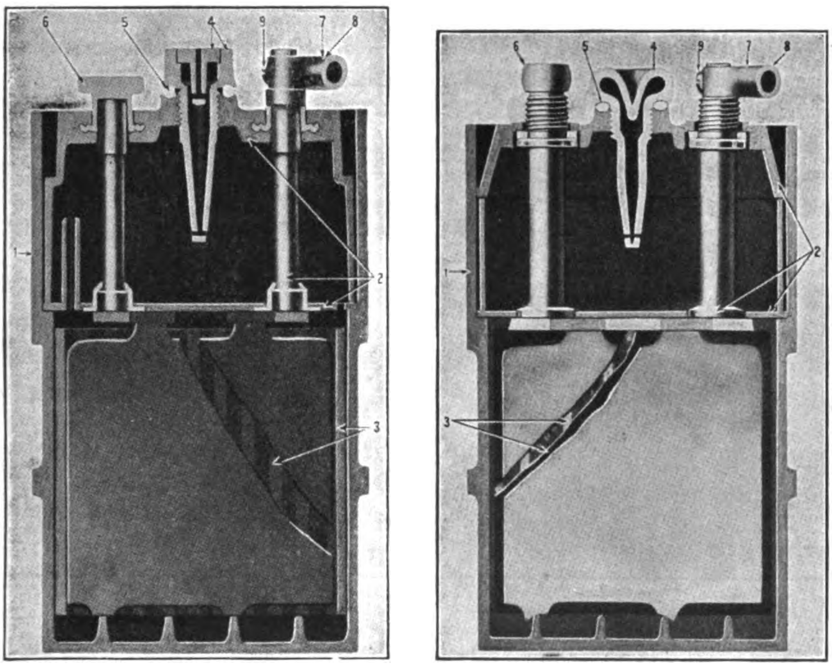

FIG. 378.—Liberty four-cell storage battery.

The perfect starter is simply a 3- or 6-cylinder, 2-cycle air engine, gear-connected to the crankshaft, and acts merely as a mechanical means of turning the engine over, depending on the regular ignition and fuel-supply systems for combustion.

Air is carried at 125 to 225 lb. pressure in a special tank and taken by separate leads to the oscillating valves in the head of each cylinder. The exhaust is directly into the air, through ports in the cylinder walls. The valves are actuated by push rods driven from an eccentric on the starter crankshaft. When used as a starter, the shaft is connected to the engine crankshaft through a gear train as follows:

A gear on the starter shaft drives another gear directly above it in the same plane by means of two idler gears. The shaft of this upper gear projects in front of it toward the engine, and is provided with a spiral key. An idler, having a spiral keyway to fit, turns up on this key when the unit is operating as a starter, until it bears against the upper gear, described above. In this position it is in mesh with a larger gear located directly below it and in front of the starter gear and carried on a jack-shaft in line with the engine crankshaft and connected to it by a spline. This gear train gives a 7 to 1 reduction from starter to engine, in order to give increased power to the starter through added speed and thus cut down required size and weight of parts.

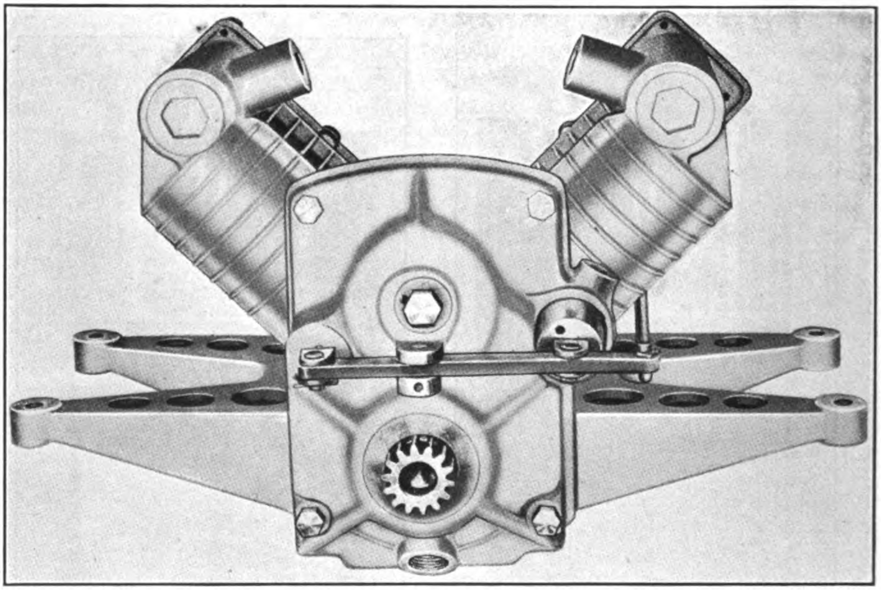

FIG. 379.—Perfect starter.

When used as a pump, the starter shaft is directly connected to the jack-shaft by a dog clutch, manually operated, and the starter shaft, whose direction of rotation is reversed, now runs at engine speed. In reversing the starter shaft, the gear shaft with the spiral keyway is also reversed and the idler riding upon it is automatically backed off out of mesh with the jack-shaft gear, thus preventing stripping of the teeth, since otherwise, this gear would be connected to both the engine and starter shafts. This action is assured through an extension of the clutch lever which starts the idler unwinding on its spiral key as the dog clutch is thrown in.

The whole starter assembly is a simple one and requires only occasional tightening up, but is at best no more than a mechanical means

of turning over the engine and it is necessary to depend wholly upon the engine's ignition and fuel-supply systems to enable it to pick up.

In installation it is necessary to see that the starter and engine shafts are lined up and that all joints are tight. Do not use shellac as it coats and scars the tubing and causes leaks. Anchor all pipes and tanks against vibration. Put a pint of heavy engine or castor oil mixed with a teaspoonful of engine graphite in the transmission case.

To use as a starter, proceed as follows:

Advance spark and open throttle so that engine will run at idling speed. Press lever on control valve which admits air to starter cylinders. Release as soon as engine picks up, otherwise air will be wasted.

To recharge tank when pressure is below 125 lb. proceed as follows:

Throttle engine down as far as possible and throw in clutch quickly by hand to prevent damage to ends of dogs, holding it until pressure has built up to 125 lb. with engine running at 1,200 to 1,400 r.p.m. It should pump up to 225 lb. in 1½ min.

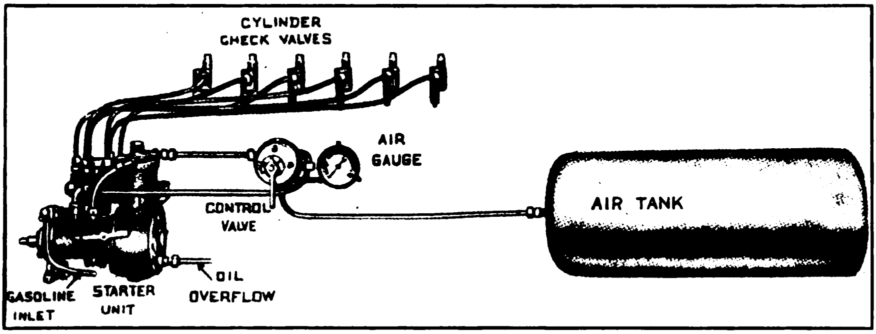

FIG. 380.—Christensen air-starter piping plan.

To recharge when pressure is above 125 lb. proceed as follows:

Throttle engine down and press button on control valve which will engage clutch by air pressure on a cylinder pinned to the clutch lever. Run engine at 1,200 to 1,400 r.p.m. A pressure of 225 lb. should be attained in 45 sec.

All safety valves are set to blow at 225 lb. In case the starter continues to pump and does not release immediately when the safety valve pops, keep engine running until clutch does release, which it should do in several revolutions after the safety valve has first popped.

The Christensen starter operates on a totally different principle. Compressed air, impregnated with gasoline to form a combustible mixture, is admitted to the cylinder on the firing stroke at about top center. With spark set at full retard a considerable amount of this air can be admitted before the spark occurs, giving a richer mixture while setting

the engine in motion. Thus the engine is not only turned over but combustion is facilitated.

In Fig. 380 yellow shows air under compression; green, air at atmospheric pressure; red, gasoline; and blue, mixture in combustion chamber.

In Fig. 381 red and white, crosshatched, shows air under compression and impregnated with gasoline. Air is led from a storage tank, where it

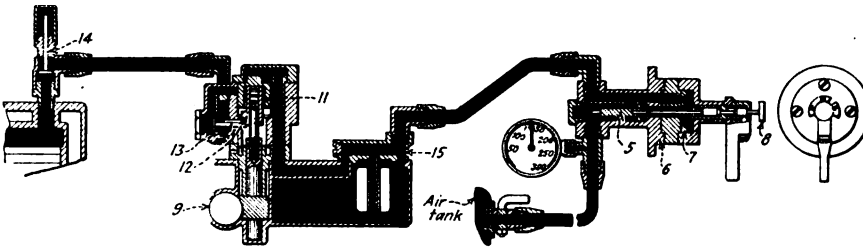

FIG. 381.—Christensen air-starter, switch on neutral position.

is kept at 125 to 250 lb. pressure, past a control valve, through a puddle carburetor connected to the main fuel-supply system of the engine, to the distributor valve. This distributor is really an assembly of valves carried in a cylindrical housing, each opening into a lead to an engine cylinder, being connected according to the firing order of the engine. The valves are opened in turn by a revolving cam driven from the engine crankshaft or camshaft which is so constructed as to give an

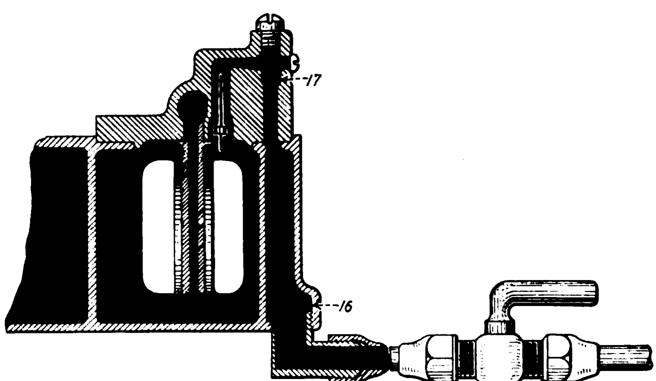

FIG. 382.—Christensen air-starter, puddle carburetor.

overlap between the closing of one valve and the opening of the next. This overlap is great enough to insure at all times a valve open into a cylinder in which the piston is past the position of spark retard. Therefore, when the air is first admitted to the starter, it will be carried directly to a cylinder in which the spark has occurred and hence, in which there can be no explosion. Therefore the mechanic can be sure

of starting out on a dead cylinder and the static friction of the engine is overcome and initial motion set up gradually without the jar and attendant strain on the moving parts incident to starting under explosion pressure.

A check valve is provided in the lead to each cylinder to prevent a backfire into the distributor-valve assembly when an explosion occurs.

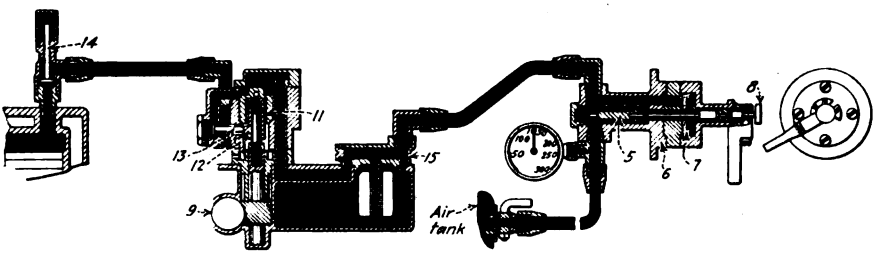

FIG. 383.—Christensen air-starter, switch on starting position.

To charge the storage tank a single-cylinder 2-cycle air compressor, driven from the engine crankshaft or camshaft, is used. The connection is made through a clutch which is manually operated, or when the pressure is above 125 lb. is actuated by air pressure acting on a piston which is worm-connected to the clutch shaft. Air is pumped back through the control valve which must be thrown to the correct position.

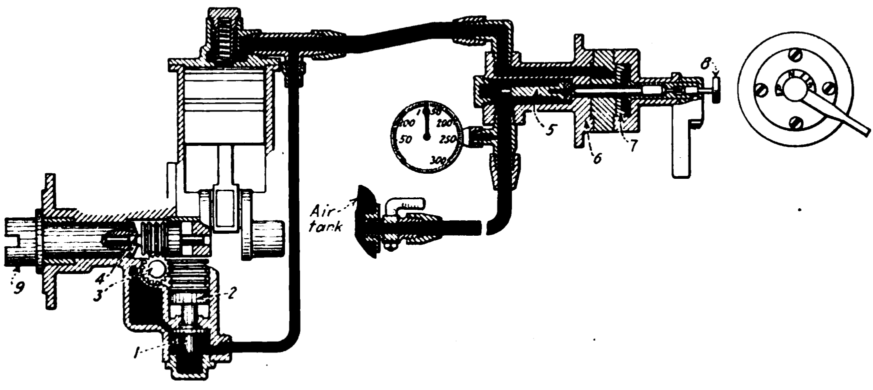

FIG. 384.—Christensen air-starter pump disengaged.

The starter mechanism is oiled by a lead from the main-engine system, the overflow returning to the oil sump.

To time the starter, proceed as follows:

1. Take cover off the distributor piston in the distributor assembly and remove piston, exposing cam.

2. Set any engine cylinder on top-center firing stroke, noting relation of direction of rotation of engine and cam.

3. Select any lead from distributor and connect to the cylinder set as above. Set cam, by turning carrying stud, so that it is just touching the

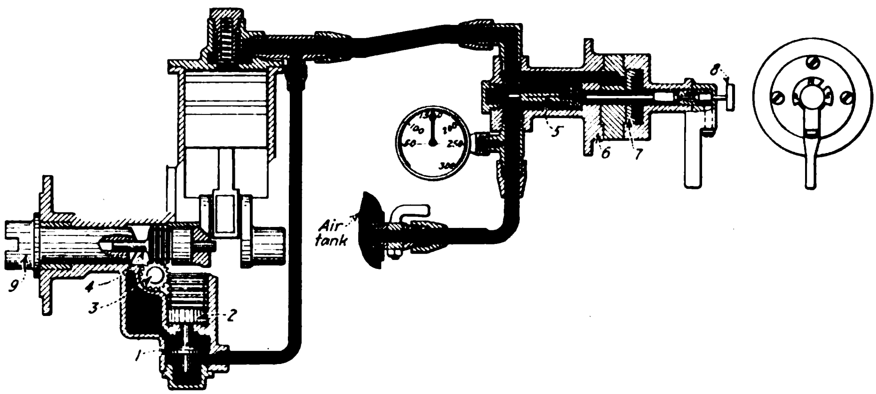

FIG. 385.—Christensen air-starter pump engaged.

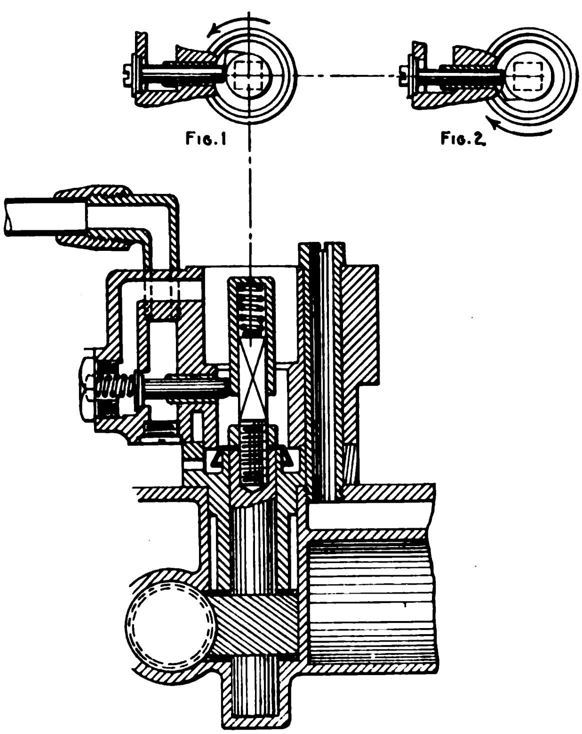

FIG. 386.—Christensen air-starter valve-actuating mechanism.

leading side of stem of valve in selected lead. Check by turning engine back and then forward, watching cam action. Ascertain if cam profile is

right to allow closing of the valve before opening of the engine exhaust valve. Replace piston and cover plate.

4. Connect other leads in order to cylinders in firing order.

Operation is as follows:

1. To start, retard spark, move starter handle to position S, and press starter button. As soon as engine picks up, release button to prevent wasting air. Move starter handle to position N, cutting off air to starter.

2. To charge tank, move starter handle to position P and idle engine. Depress starter button, admitting air to clutch piston, and throw in clutch. If air pressure is not sufficient to engage clutch, it may be thrown in by hand. Release button and speed engine up to not over 1,200 r.p.m. When required pressure of 225 to 250 lb. is reached, as shown by gage on tank, return starter handle to position N, cutting off air connection to tank, and hence to clutch piston, and opening pump discharge to the atmosphere. In some cases, where it is desired to run the pump continuously, automatic engaging and disengaging devices may be fitted.

221. Detail Specifications of Fuel-supply System. The course of the fuel is as follows:

Tanks to Carburetor. On the HS boats the main-supply tanks are connected in parallel and with the gravity tanks by two lines: a delivery, in which is located the wind-driven gasoline pump and a return or overflow. There is a valve in each line at the tank connection and one in the delivery line ahead of the pump. The auxiliary hand pump is located in a bypass around the main delivery pump.

The inlet connection to the gravity tank is in the bottom, at the gear end, and the overflow is similarly placed at the propeller end. Thus, in nosing down at any appreciable angle, with the flat-bottomed tank on the HS-2L boat, the carburetor connection at the gear end of the tank is uncovered, since the overflow carries off the excess level thrown over it. To assure a constant supply to the front carburetor, a small 1-gal. tank has been fitted into the vee of the engine in front of the carburetor. The main delivery pump feeds into this tank which has smaller connections, one at the side direct to the carburetor and one at the top to the gravity tank. The combined area of these outlets is less than that of the inlet, thus maintaining a pressure in the tanks. This arrangement gives a direct and positive feed to the carburetor and to the gravity tank at all times.

Carburetor to Cylinders. The carburetor barrels are directly connected to the bottom sides of the inlet manifolds, the opening being in the center of the manifold section, directly opposite the opening to the center cylinder of the three, fed by the manifold section. Thus it is necessary to insert a baffle-plate across this opening and, by forcing the mixture around the ends of it, make the paths to each of the three cylinders equal in length and so equalize the mixture distribution to all.

The top of each manifold casting is a separate chamber, provided with three inlets from the water outlets of the three cylinders fed by that section. There is also one outlet opposite, which conveys the water to the water outlet header. All cooling water, then, passes across the top of the gas passages while at its highest temperature. The mixture, entering at the bottom of the manifold, is carried by its inertia against the top of the gas passage and, spreading out under it, absorbs the heat given up by the water. Thus it is necessary to pass the water only over the top of the gas passage; hence, minimum obstruction to flow, as will be discussed later.

222. Detail Specifications of Cooling System. Description of course of water.

Radiator to Pump. The pump suction line from the radiator is 1¾ in. in diameter and, passing under the engine, from a front-type radiator,

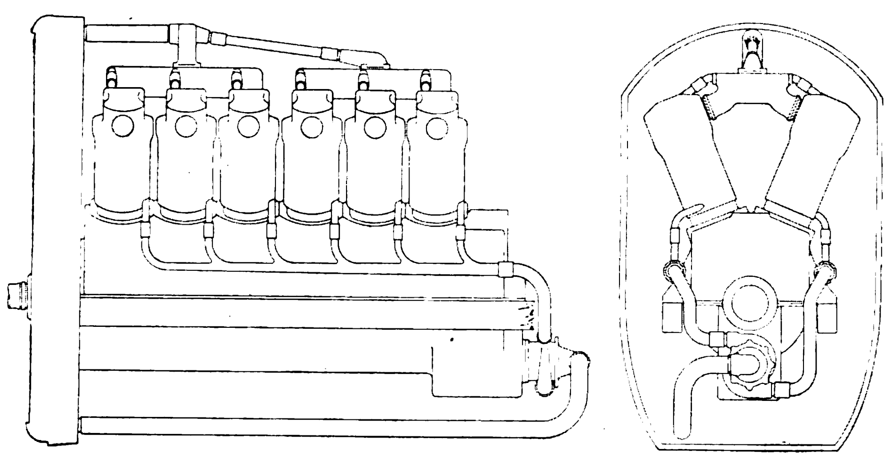

FIG. 388.—Cooling system, Liberty engine.

doubles upward and backward, entering the pump housing directly in the center of the front cover plate.

Pump to Cylinder Jackets. The two pump outlets are tangential, 1⅛ in. in diameter and connect directly to Russian iron headers, one for each bank of cylinders, the diameter of which gradually decreases from 1¾ in., at the pump connection, to ½ in., at the No. 6 cylinder connection, thus offsetting the loss of quantity, to the several cylinders, by a reduction of cross-sectional area and keeping pressure constant. This arrangement insures equal supply to all cylinders. All hose connections must be tapped and shellacked and the tape should extend well back over each pipe to give a greater margin of safety in case of pipe failure.

In Cylinder Jackets. The inlet connections, ½ in. in diameter, are

tangentially placed in the water jackets, thus insuring from the start a whirling motion of the water around the cylinder and preventing any tendency to stream from inlet direct to outlet. This whirling motion is maintained by the annular ribs on the outside of the cylinder barrels which offer an obstruction to direct flow.

The outlet pipe, ½ in. in diameter, extends well down into the water space over the cylinder head to a point near the exhaust-valve cage in order to take off the hottest water, which will, of course, be found at this point. To insure, however, that no air or steam pockets form around

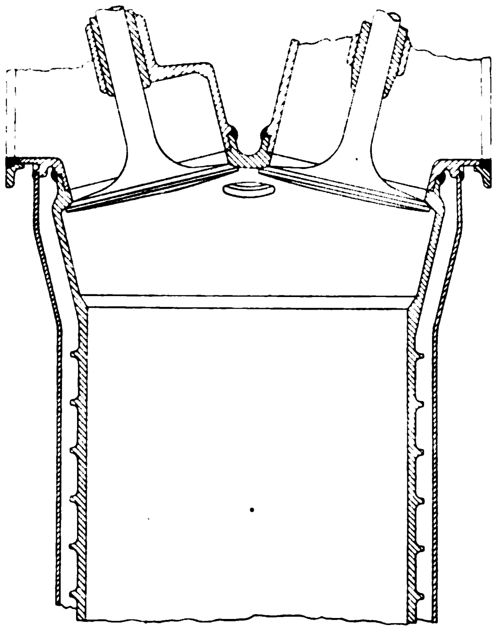

Fig. 389.—Detail of water space over combustion head, Liberty engine, showing position of outlet and provision for cooling of exhaust-valve sleeve.

the inlet-valve cage, which is the highest point of the cylinder due to the angle at which it is set, an annular ring of holes is drilled in the outlet pipe where it passes this point, to allow escape of the water if necessary.

From Cylinder Jackets to Radiator. The outlets from the cylinder jackets discharge into the jacket space on top of the inlet manifolds and the flow is always in the same horizontal plane to an outlet on the opposite side, so that there is little obstruction, and, as all the mixture comes in contact with the bottom of the water passage, the design is a very efficient one. The outlets from the jacket spaces of opposite manifold sections discharge together into the radiator header connections, a 1⅛-in. pipe being provided for the discharge from the front cylinders, increasing to 1¾ back of the connection from the rear cylinders.

The system exclusive of radiator and its connections holds 5½ gal. of water. With the front-type radiator used on the HS-1L and HS-2L boats there is an added capacity of 13 gal., so that the entire system holds 18½ gal. With a rated pump capacity, with a free outlet of 100 gal. per min. means that the water is circulated approximately five times in that length of time.

The temperature should be kept between 150° F. and 170° F., with a maximum of 180° F. However, no engine should be considered warmed until the temperature is at least 140° F., or 160° F. in cold weather. This is not a sure test of proper engine condition, but no engine should be used in flight until these temperatures are reached.

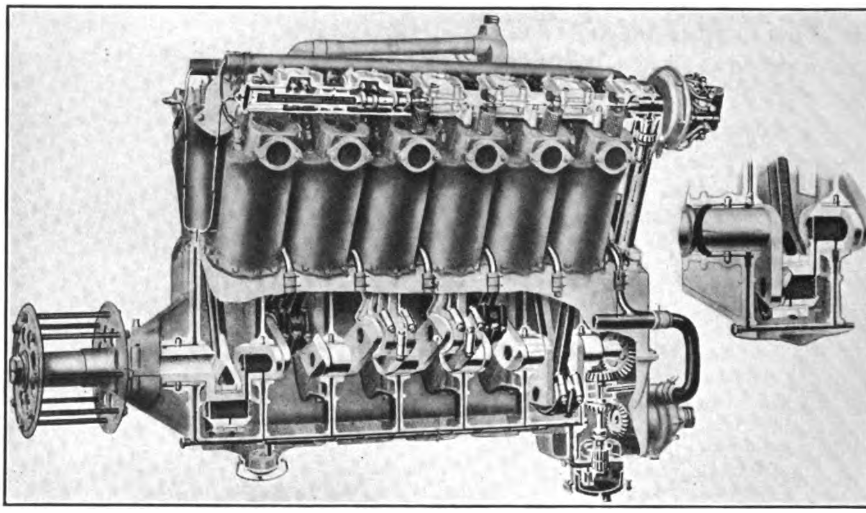

Fig. 390.—Lubrication chart, Liberty engine.

223. Detail Specifications of Lubricating System. This engine operates with a dry sump, that is, the oil, as it drains back into the shallow crankcase, is immediately pumped out to external storage tanks, this arrangement giving increased facilities for cooling.

Description of Course of Oil.

Tanks to Pump. Oil flows by gravity from the storage tanks to the delivery-pump inlet connection and is screened in the pump housing before entering the gears. This 2-gear pump delivers the oil past the pressure release valve to the main oil lead carried in the trough in the bottom of the lower section of the crankcase.

From Pump to Various Engine Parts. Branch leads from the main lead pass up through the lower case webs and enter the main bearings in the center of the lower half of the bushings, the hollow lead acting as a dowel pin.

The excess oil from the bearings passes into the hollow main journals through radial holes, one to each journal, and is forced up holes drilled in the crank-throws, by centrifugal force due to rotation. It passes out through radial holes in these pin journals to the crankpin bearing surfaces and then through holes in the bushings to the plain rod bearing surfaces.

The excess oil from these bearings is whirled off in a spray or fog, lubricating the cylinder walls and wristpin bearings.

The propeller end of the main lead is provided with a removable screw plug, giving access to the lead for cleansing or inspection.

The vertical lead to No. 7 main bearing divides just below it, so that the excess oil passes around the bearing bushing and up through a cored passage in the rear crankcase wall to a 3-way connection on the deck. From here two external leads, one up the end of each bank, carry the oil to the camshafts. The third connection is that for the oil pressure gage. The oil enters the camshaft housings axially and, passing back of the rear camshaft bearing bushings, enters the bearing spaces through radial holes in the bushings. The excess oil enters the hollow shafts through radial holes in the journals and flows forward through the shaft, lubricating the other bearings through similar holes in their journals. The excess passes out through a hole in the bottom of No. 1 bearing into the driveshaft housings. The overflow from the bearings collects in the bottom of the housing to a depth of $\frac{1}{4}$ in., the level being determined by the height of the slots in the bearing supporting webs and the final overflow into the driveshaft housing along with the overflow from the camshaft, as above.

The revolving cams dip into the oil bath, lubricating their surfaces and those of the cam followers, also throwing the oil against the oscillating rocker-arm journals through slots in the inner sides of their bearings.

These journals are no longer hollow and do not carry the oil, which dropped from the roof of the housing, to the bearing surfaces through radial holes, as in the early engines.

The excess oil from the camshaft assembly flows down over the driveshaft assembly, lubricating it and collects in the gear chamber.

The oil passes from the gear chamber to the return side of the pump, directly below it, through a screen and is forced to the storage tanks. The oil which drains from the main and crankpin bearings and cylinder walls collects in the sediment sump near the propeller end of the crankcase, whence it is drained by the return pump, through a screen and also forced to the storage tanks.

An oil trap in the floor of the gear chamber seals the crankcase at this point and prevents breathing through the camshaft housing. It also prevents the oil vapor from entering the pump, a second trap in the top side of the gear chamber providing a vent for it.

Ordinarily the use of the external storage tanks provides a sufficient means for cooling the oil, though in very hot weather it may not keep the oil as cool as desired. However, the Pensacola maximum is only 170° F. which, while higher than desired, is not serious.

The pressure release valve consists of a flat-faced piston which bears on a removable seat in a bypass of the pump delivery line, being held against this seat by a helical spring whose tension may be adjusted by screwing in or out its retaining collar against washers of varying thickness. Great care should be taken to see that this seat is firmly in place after assembly or adjustment or oil may leak under it and, acting on the increased area, cause the valve to open at a much lower actual pressure than that for which it was set. The overflow from this valve drains back into the lower part of the pump housing whence it is pumped over again with the oil coming from the tanks. The valve head is drilled with four $\frac{1}{32}$-in. holes to provide a constant overflow since the pump would otherwise maintain too high a pressure for the new requirements but they may be plugged, and one or more often must be plugged, in order to obtain the desired results.

The oil-pressure gage connection is taken from the 3-way elbow on the crankcase deck, as described above. At this point the oil has passed through all the main bearings and hence has performed its most important single function. Therefore, if there is a correct pressure reading here the pressure, has been correct up to this point. This, then, is the proper place for the gage connection.

The oil-temperature gage connection is properly located in the discharge line of the oil return-pump, giving at this point the temperature of the oil immediately after it has passed through the engine and hence, the maximum.

Amount of Oil Used. The engine requires about .03 lb. per hp.-hr., or about 1.5 gal. per hr. of flight with wide open throttle. The system carries about 12 gal. which is enough for an 8-hour flight, the oil storage capacity being greater than the fuel supply. In preparing an engine for service the storage tanks are filled to about two-thirds of their capacity, $8\frac{1}{4}$ gal., and in addition about 3 gal. are poured into the crankcase through the breather tubes and 1 pt. is put into the camshaft housing giving a total of about 12 gal.

Rate of Turnover. There is no information available on this point.

Oil Temperature. The oil should be kept between temperatures of 120° F. and 130° F. in order to obtain best results, although temperatures of as high as 170° F. have been maintained without showing harmful results.

The pressure should be:

8 lb. at idling speed, which is about 700 r.p.m.

25 to 30 lb. with an allowable maximum of 35 lb. at wide-open throttle, which is about 1,700 r.p.m.

Engine Testing.

224. General Features. Aircraft engines are given a rigid test before they are installed in a plane. This test is conducted on a specially constructed test stand which is rigid and is usually built on a concrete foundation. The engine is supported on two longitudinal beams which correspond to the engine beds of the fuselage. It is equipped with fuel supply, cooling-water supply and oil supply systems which are provided with various measuring instruments including tachometer, pressure gages and thermometers. Several methods of determining the horsepower may be used. The two methods which are in general use are the calibrated club and torque dynamometers.

225. Description of Club Method. The calibrated-club method is the more popular on repair bases as it requires very little equipment. A standard propeller, or a club roughly shaped like a propeller, except that it has no pitch, is used as a load on the engine. The club has been previously calibrated on an electric dynamometer, to determine the horsepower required to drive the club at various speeds. From the date secured a characteristic curve of this club is drawn. With this club attached and rotating at any speed, the horsepower being developed can be readily found by referring to the curve.

The calibration is usually done under or corrected to a standard temperature of 32° F., and a barometric pressure of 29.92 in. Since the density of the air has a direct effect on the number of r.p.m. which the propeller will turn and since this density varies with the pressure and temperature, the measured horsepower must be corrected for the atmospheric conditions under which the engine is operating. It has previously been explained that the relative density of the air varies directly as the absolute pressure and inversely as the absolute temperature, as shown in the following equation:

$$\text{True hp.} = \text{measured hp.} \times \frac{\text{recorded pressure (lb.)}}{\text{standard pressure (lb.)}} \times \frac{\text{standard temperature (lb.)}}{\text{recorded temperature (lb.)}}\cdot$$

The recorded pressure and temperature are those under which the engine operated during the test and the standard pressure and the temperature the ones under which the club was calibrated.

226. Description of Torque Stand Method. The torque measuring stands suitable for the testing of aircraft engines include the water-brake and the electric dynamometer. Water-brake dynamometers are of two types. One arrangement is similar in principle to a centrifugal pump, the casing being balanced and supported in the pump shaft. An attached brake-arm, supported on scales, measures the turning moment. This is the Fronde or ordinary water brake, which differs from a cen-

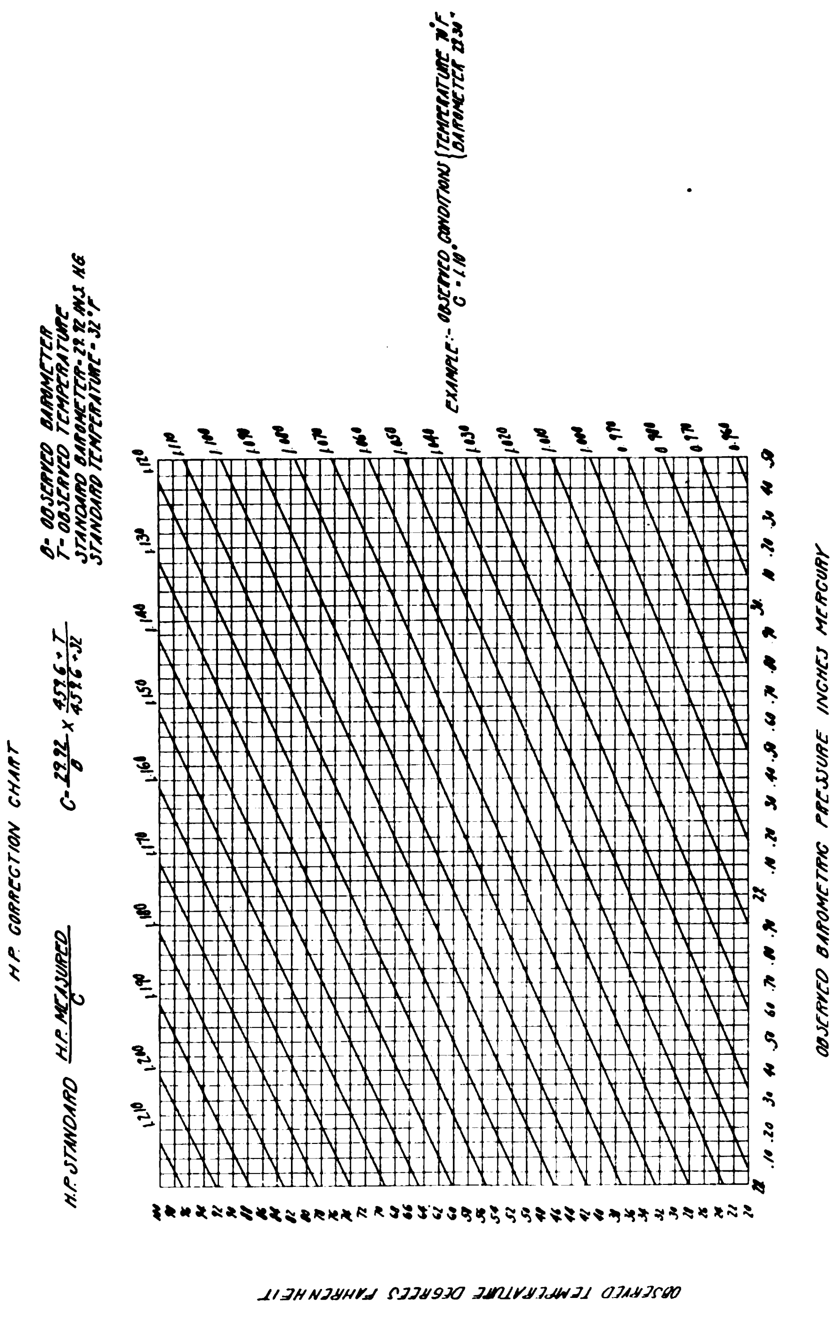

Fig. 391.—Horsepower correction chart.

trifugal pump in that the runner is made with deep recesses to increase the resistance. The tendency is to carry the casing around in the direction of rotation. Let Wo be the weight of the arm on the scales when the runner is stationary and W the weight when it is being turned by the engine. Then $W - Wo$ is the net weight on the scales, produced by the turning moment. If l is the length of the arm in feet, and n the revolutions per minute of the engine, the power developed may be computed by the following formula:

$$\text{Brake hp.} = \frac{2\pi ln.(W - Wo)}{33{,}000}.$$

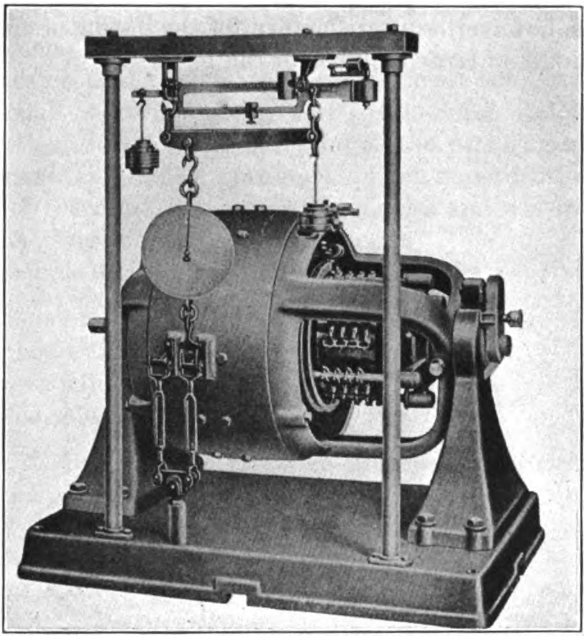

FIG. 392.—Electric dynamometer.

The Westinghouse turbine hydraulic dynamometer is a second type. It is essentially a double-flow turbine with blades shaped to produce great resistance to flow. The casing is balanced on the shaft and provided with a brake-arm the same way as in the Fronde dynamometer. Power is also calculated in the same way.

Electric Cradle Dynamometer. This is a generator whose field is mounted on a cradle supported on trunnions and whose armature shaft is mechanically connected to the engine being tested. The pull exerted between the armature and field tends to rotate the field. A lever arm on the field casing measures this turning moment on a scale as in the case of the water dynamometer. Power is also computed in the same way.

It will be noticed that two readings are necessary in all of these torque measuring methods, the weight on the scales, and the revolutions per minute of the engine, and in addition, the length of the brake-arm and the weight of the arm on the scales when the engine is stationary. On the other hand, with the calibrated-club method, only the revolutions per minute need be known to read off the horsepower output. However, the torque measuring dynamometers give more accurate results, and need no corrections for temperature or pressure as in the case of the water-brake dynamometers. In the electric dynamometer the result must be corrected for the copper, (I^2R), loss in the armature and field, and, for very accurate results, the temperature must be taken into consideration. All methods, however, are satisfactory for the testing of aircraft engines within the limits of error required in the results.

CHAPTER VII

AIRCRAFT ENGINE PROBLEMS

Problems to be Solved.

The object of this subject is to work out numerical problems based on the work of Subjects II and III and to bring out in arithmetical form the principles involved in these subjects.

The engines on which calculations are made are the Curtiss OXX-2, Curtiss V-2, Hall-Scott A-7, Liberty, Hispano-Suiza and the Gnome. In the course the instructor will figure out all the problems at the board using the Curtiss OXX-2 as an example. Each man of the class will be assigned one of the other five remaining engines and will work out the same problems using the data of his engine.

Each problem is divided into (4) parts:

1. Statement.
2. Method of solution.
3. Known values.
4. Actual solution.

227. Prob. 1. Brake Mean Effective Pressure. 1. *Statement.* Calculate the mean effective pressure (m.e.p.) with respect to brake horsepower (b.hp.). Solve for Curtiss OXX-2 engine.

2. *Method of Solution.* Given the formula

$$\text{Hp.} = \frac{PLAN}{33{,}000}$$

where
P = brake m.e.p. in pounds per square inch.
L = length of stroke in feet.
A = area of piston in square inches.
N = number of power strokes per minute.

In a 4-cycle engine $N = \frac{\text{r.p.m.}}{2} \times$ number of cylinders. In this problem the brake m.e.p. is to be found, having as known value b.hp. Multiplying both sides of the equation $\left(\text{Hp.} = \frac{PLAN}{33{,}000}\right)$ by 33,000 and dividing both sides by LAN,

$$P = \frac{33{,}000 \text{ hp.}}{LAN}$$

3. *Known Values.*

Known values are Hp. = 100 at 1,250 r.p.m.

$$L = 5 \text{ in.} = .416 \text{ ft.}$$
$$A = \text{piston area} = 14.19 \text{ sq. in.}$$
$$N = \frac{\text{r.p.m.}}{2} \times \text{No. of cyl.} = \frac{1250}{2} \times 8 = 5{,}000.$$
$$\text{Mech. effy.} = 85 \text{ per cent.}$$

4. *Solution.*

$$P = \frac{100 \times 33{,}000}{0.416 \times 14.19 \times 5{,}000}$$
$$= 112 \text{ lb. per sq. in.}$$

This value is the brake m.e.p. The next step in the solution of the problem is to determine the actual or indicated m.e.p.

$$\frac{\text{B.hp.}}{\text{I.hp.}} = \text{mech. effy.}$$

or

$$\frac{\text{B.hp.}}{\text{Mech. effy.}} = \text{i.hp.}$$

In the formula

$$\text{Hp.} = \frac{PLAN}{33{,}000}$$

Hp. and P are the only variables. Hp. varies as P. Consequently if the i.hp. varies with the mech. effy. as shown above the i.m.e.p. will vary exactly the same way.

Therefore

$$\frac{\text{Brake m.e.p.}}{\text{Mech. effy.}} = \text{indicated m.e.p.}$$

Then

$$\frac{112}{.85} = 132 \text{ lb. per sq. in.,}$$

the m.e.p. developed by the Curtiss OXX-2 engine.

228. Prob. II. Mean Piston Speed. 1. *Statement.* Calculate the mean piston speed for the Curtiss OXX-2 engine.

2. *Method of Solution.* Mean piston speed is the average rate of travel or the distance that the piston travels in one minute.

Mean speed = $2LN$

where

$$L = \text{stroke in feet.}$$
$$N = \text{r.p.m.}$$

3. *Known Values.* Known values are

$$L = 5 \text{ in.} = .416 \text{ ft.}$$
$$N = 1{,}250 \text{ r.p.m.}$$

4. *Solution.*

$$\text{Mean speed} = .416 \times 1{,}250$$
$$= 1{,}040 \text{ ft. per min.}$$

The average piston speed is of interest as it is a measure of the time for continuous operation. With cast-iron pistons and iron cylinders the limit of piston speed for continuous operation is about 1,000 ft. per min. Aircraft engines have a much higher piston speed but this is permissible as they generally have aluminum pistons in steel cylinders and their time for operation, even at full power, is comparatively short. Engines are periodically overhauled and parts are replaced. The ultimate limit of piston speed is the point where the oil film is destroyed between the rubbing surfaces.

229. Prob. III. Thermal Efficiency. 1. *Statement.* Calculate the thermal efficiency of the Curtiss OXX-2 engine from the measured fuel consumption.

2. *Method of Solution.* Thermal efficiency is the ratio of work done by the engine to the heat of the fuel used, both being measured in the same units, either foot-pounds or B. usually the latter.

$$\text{Thermal efficiency} = \frac{\text{output}}{\text{input}}$$

$$\begin{aligned}
\text{Output one hp.} &= 33{,}000 \text{ ft.-lb. per min.} \\
&= 33{,}000 \times 60 = 1{,}980{,}000 \text{ ft.-lb. per hr.} \\
778 \text{ ft.-lb.} &= 1 \text{ B.} \\
&= \frac{1{,}980{,}000}{778} = 2{,}545 \text{ B. per hr.}
\end{aligned}$$

$$\begin{aligned}
\text{Input} &= W \times H \\
\text{where} \quad W &= \text{lb. of gasoline per hp. per hr.} \\
H &= \text{heating value of 1 lb. of gasoline} \\
&= 18{,}320 + 40\,(\text{Bé} - 10) \text{ expressed in B.} \\
\text{Bé} &= \text{Baumé gravity of gasoline.}
\end{aligned}$$

$$\text{Summation Thermal efficiency} = \frac{2{,}545}{WH}$$

3. *Known Values.*

$$W = .646$$
$$\text{Bé} = 62°$$

4. *Solution.*

$$H = 18{,}320 + 40\,(62 - 10) = 20{,}400$$

$$\text{Thermal efficiency} = \frac{2{,}545}{.646 \times 20{,}400} = .1935 \text{ or } 19.35 \text{ per cent}$$

230. Prob. IV. Rate of Heat Generation. 1. *Statement.* Calculate the rate of heat generation in the combustion chamber of a gasoline engine. Solve for typical aircraft, automobile and marine engine.

2. *Method of Solution.* The combustion chamber of a gasoline engine compares with the grate of a boiler. In the latter, the common unit is the weight of coal burned per hour per square foot of grate surface. In the gasoline engine it is the weight of gasoline burned per square inch of

combustion surface per minute. It is rather difficult to figure the area of the conbustion chamber, so for simplicity and ease of calculation the rate of heat generation per square inch of piston area is calculated. In this way one engine can be compared with another on a uniform basis.

Formula:

$$U \times H = \text{B.t.u.'s generated per hr.}$$

where, U = fuel consumption in lb. per hr.

and H = heating value of fuel in B.t.u.'s per lb.

$$\frac{U \times H}{N} = \text{B.t.u.'s generated per cyl. per hr.}$$

where, N = No. cyl.

$$\frac{U \times H}{N \times A} = \text{B.t.u.'s generated per hr. per sq. in. of piston area.}$$

where, A = piston area in sq. in.

therefore $\dfrac{U \times H}{N \times A \times 60}$ = B.t.u.'s generated per min. per sq. in. of piston area.

3. *Known Values.*

TABLE XXVII.—ENGINE COMPARISON TABLE

	Curtiss OXX-2 (aircraft)	Standard (marine)	Ford (auto)
U	64.6 lb. per hr.	160 lb. per hr.	10.8 lb. per hr.
H	20,400 B.t.u. (62° Bé.)	20,400 B.t.u. (62° Bé.)	20,400 B.t.u. (62° Bé.)
N	8 cylinders	6 cylinders	4 cylinders
A	14.19 sq. in. (4.25-in. bore)	78.54 sq. in. (10-in. bore)	11.04 sq. in. (3.75-in. bore)

4. *Solution.*

Curtiss OXX-2.

$$\text{Rate} = \frac{64.6 \times 20{,}400}{8 \times 14.19 \times 60} = 193 \text{ B.t.u. per sq. in. of piston area per min.}$$

Standard.

$$\text{Rate} = \frac{160 \times 20{,}400}{6 \times 78.54 \times 60} = 115 \text{ B.t.u. per sq. in. of piston area per min.}$$

Ford.

$$\text{Rate} = \frac{10.8 \times 20{,}400}{4 \times 11.04 \times 60} = 83.1 \text{ B.t.u. per sq. in. of piston area per min.}$$

From the above results, it is evident that the aircraft engine has the highest rate of heat generation per square inch of piston area. The high rate makes the problem of heat control more difficult in the aircraft engine than in other types. It increases the problem of valve and spark-plug design. A valve or spark plug which may work perfectly in a Ford may be entirely unsuited for the Curtiss, in fact, it would probably burn up.

231. Prob. V. Plotting Compression and Expansion Line. 1. *Statement.* (*a*) Plot theoretical compression line and compute the average pressure under the line. Also compute the per cent. clearance from the compression pressure.

(*b*) Plot a theoretical expansion line and find the average pressure under the line.

(*c*) Calculate the maximum explosion pressure from average pressure found under compression and expansion lines, using m.e.p. found in Prob. I. Solve for Curtiss OXX-2 engine.

Method of Solution and Solution. The compression line is adiabatic, following the law,

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^s.$$

in which P_1 = initial pressure.
where, P_2 = final pressure.
V_1 = initial volume.
V_2 = final volume.
s = exponent of compression, varying from 1.33 to 1.406.

To avoid the use of logarithms and to simplify the working of this problem, Table XXVIII has been calculated. $\frac{P_2}{P_1}$ is assumed from 1 to 10 and the various volume ratios computed for both values of s, minimum value 1.33, and maximum value 1.406. The expansion line follows the same law but more nearly approaches the maximum value of s, so is only figured for 1.406.

To plot compression line, refer to Table XXVIII and Table XXIX. Assume volume of cylinder clearance plus displacement to be 1 cu. ft., and pressure at the start of the compression to be 14.5 lb. per sq. in. This gives the starting point a of the curve. Next assume the pressure to be double. From Table XXVIII look down the column headed "Pressure Increase" until 2.0 is reached, corresponding to doubled pressure. The volume decrease corresponding to this figure, under heading of medium, is .595. This means that when the pressure is double or brought up to 2 × 14.5 or 29 lb. per sq. in., the volume in the cylinder is reduced to .595 of its former value or to .595 cu. ft. Plotting these two values determines point b. Assume 3, 4, 5, 6, 7, 8 and 9 compressions, look up the corresponding volumes and locate points c, d, e, f, g, h and j. Draw a smooth curve through these points. This is the compression curve. This should be repeated, using the same pressure values, but using the maximum values for the volume, giving another curve. The real compression curve lies somewhere between the two. For the balance of this problem use only the curve plotted with minimum values.

The end of the compression curve is the point where the compression pressure of the engine is reached. For the Curtiss OXX-2 the compres-

sion pressure is 90 lb. gage or 104.7 lb. per sq. in. absolute. At this pressure, draw a horizontal line *mn* on the diagram, and at the point *n*, where it intersects the compression curve, draw a vertical line *np*. This line shows the clearance volume. It intersects the horizontal axis at a point where the volume equals .226 cu. ft. Total clearance volume plus displacement equals 1 cu. ft. Therefore, displacement is equal to 1 − .226, or .774 cu. ft. Clearance is calculated as per cent. of displacement.

$$\text{Clearance} = \frac{.226}{.774} = 29.2 \text{ per cent. of displacement.}$$

To find the average pressure under the curve the mean ordinate method is used. This method is described under Subject II, "Indicator and the Indicator Diagram." After the average pressure under the curve is found, it is divided by the initial pressure, 14.5 lb. per sq. in., and a ratio of average to initial pressure is found. This will vary with the compression pressure of the engine, and the result the student obtains from his drawing should be compared with Table XXXI which gives the correct ratios calculated mathematically. Possible differences will be due to inaccuracies in drawing and to the inaccuracy of the mean ordinate method. The figures in the table are the ones to be used.

(*b*) The expansion line is plotted directly from the figures in Table XXVIII, "Pressure Decrease" against "Volume Increase." This is shown in Table XXX. To determine the end of the curve it is merely necessary to take the reciprocal of the volume at the end of compression. From Table XXIX this was .226. Then the volume at end of expansion is $\frac{1}{.226}$ or 4.425.

A line *ab* is drawn at that volume, as in Table XXX, and the point *a* is located at the end of the expansion line.

The average pressure under the line is found in the same manner as for the compression line, and then compared with the calculated values; see Table XXXI.

(*c*) To calculate maximum explosion pressure.

Known Values.

Initial pressure = 14.5 lb. per sq. in. (absolute).

Compression pressure = 90 lb. per sq. in. (gage).

M.e.p. (indicated) from Prob. I = 132 lb. per sq. in.

Solution.

Average pressure under compression line, shown by *a* in

$$\text{Fig. 401,} = \text{ratio of } \left(\frac{\text{average pressure}}{\text{initial pressure}}\right) \times \text{initial pressure.}$$

From Table XXXI we find that for the Curtiss OXX-2 this ratio is 2.53; therefore, the average pressure under the compression line = 2.53 × 14.5, or 36.7 lb. per sq. in.

M.e.p. of card from Prob. I = 132 lb. per sq. in.

The average pressure under the expansion line = 36.7 plus 132, or 168.7 lb. per sq. in. It is apparent that the average pressure under expansion line = ratio $\left(\frac{\text{average pressure}}{\text{initial pressure}}\right) \times$ initial pressure.

That is,

$$168.7 = .350 \times \text{initial pressure},$$

or

$$\text{initial pressure} = \frac{168.7}{.350} = 480 \text{ lb. per sq. in.}$$

Since the initial expansion pressure is the same as the maximum explosion pressure, this result of 480 lb. per sq. in. is the result desired.

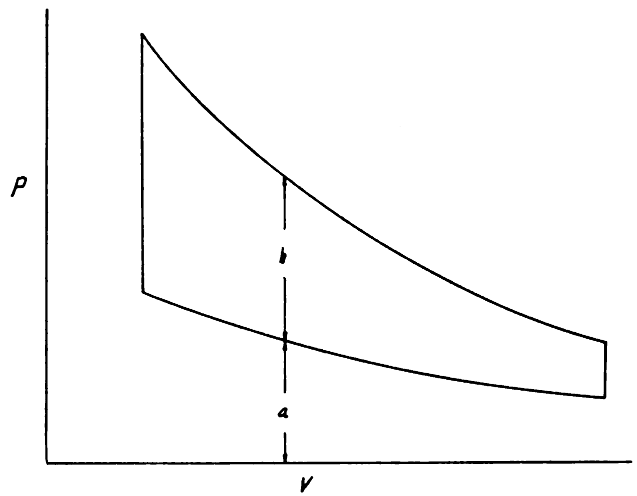

Fig. 393.—Theoretical indicator card.

232. Prob. VI. Temperature at End of Compression. 1. *Statement.* Calculate the temperature at the end of compression for the Curtiss OXX-2 engine, assuming varying initial temperatures and determine final suction temperature which would cause sure detonation.

2. *Method of Solution.*

$$\frac{\text{Pressure at end of compression}}{\text{Pressure at start of compression}} = \text{compression ratio.}$$

From Table XXVIII get the temperature ratio corresponding to compression ratio for both maximum and minimum values, interpolating if necessary.

Initial temperature 460° F. = initial temperature, absolute.

Initial temperature absolute × temperature ratio equals final temperature absolute.

Final temperature absolute − 460° = final temperature ° F.

3. *Known Values.*

Initial temperatures of 40°, 140°, 240°, 340° F. are assumed.

Initial pressure = 14.5 lb. per sq. in., absolute.

Final compression pressure = 90 lb. per sq. in. (gage).

Detonating temperature = 986° F.

4. *Solution.*

This problem is solved for the minimum value of *s* only.

Pressure at end of compression = 90 + 14.7 = 104.7 lb. per sq. in.

Pressure at start of compression = 14.5 lb. per sq. in.

$$\frac{104.7}{14.5} = 7.22 \text{ or compression ratio.}$$

From Table XXVIII this corresponds to temperature ratio of 1.64, minimum value. This value must be secured by interpolation.

Assuming an initial temperature of 40° F., the initial temperature, absolute, will be 40° + 460° = 500°.

500° × 1.64 = 820° absolute, the final temperature.

820° − 460° = 360°, which is the final temperature F.

Solving for other initial temperatures:

140° + 460° = 600° × 1.64 = 984° − 460° = 524° F., the final temperature.

240° + 460° = 700° × 1.64 = 1,148° − 460° = 688° F., the final temperature.

340° + 460° = 800° × 1.64 = 1,312° − 460° = 852° F., the final temperature.

440° + 460° = 900° × 1.64 = 1,476° − 460° = 1,016° F., the final temperature.

This table shows the effect on final temperature by adding heat, thus increasing the initial temperature. In the last case an initial temperature of 440° F. gives a final temperature of 1016° F., which is above the detonating temperature of 986° F. Therefore, a suction temperature of 440° F. cannot be used. To find the highest suction temperature which may be used it is merely necessary to reverse the problem, for example:

$$986° - 460° = 1446° \div 1.64 = 882° - 460° = 422°.$$

Therefore, 422° F., is the highest initial temperature which can be used.

NOTE. Maximum values from Table XXVIII should be worked by the class, if time is available.

233. Prob. VII. Average Velocity of Mixture Through Manifold. 1. *Statement.* Calculate the average velocity of mixture through the inlet manifold of the Curtiss OXX-2 engine, assuming 100 per cent. volumetric efficiency.

2. *Method of Solution.*

(a) $$Q = \frac{A \times L}{1{,}728} \times N \times \frac{\text{r.p.m.}}{2}$$

where,
Q = total suction displacement in cu. ft. per min.
A = area of bore in sq. in.
L = length of stroke in in.
N = number of cylinders.
R.p.m. = revolutions per minute.
1,728 = number of cubic in. in 1 ft.

(b) $$D = \frac{Q}{60 \times n}$$

where,
D = cu. ft. displacement per manifold per sec.
60 = number of seconds in one minute.
n = number of manifolds on engine.

(c) $$V = \frac{Q}{a}$$

where,
a = area of manifold on sq. ft.
V = average velocity of mixture in inlet manifold in ft. per sec.

3. *Known Values.*

A = area $4\frac{1}{4}$ in. bore = 14.19 sq. in.
L = 5 in.
N = 8.
R.p.m. = 1,250.
n = 2.
a = area $1\frac{9}{16}$ in. manifold passage = .0133 sq. ft.

4. *Solution.*

(a) $$Q = \frac{14.19 \times 5}{1{,}728} \times 8 \times \frac{1{,}250}{2} = 205 \text{ cu. ft. per min.}$$

(b) $$D = \frac{205}{60 \times 2} = 1.71 \text{ cu. ft. per min. per manifold.}$$

(c) $$V = \frac{1.71}{.0133} = 128 \text{ ft. per sec.}$$ = the velocity in the manifold of the Curtiss OXX-2 engine.

This value is the average velocity of mixture passing through the inlet manifold. It is not very accurate as there should be account taken of volumetric efficiency, wall friction of the manifold, and effect of bends in the pipe. It, however, gives an indication of the velocity and forms a basis for comparison.

234. Prob. VIII. Pressure Due to Velocity of Mixture Through Manifold. 1. *Statement.* Calculate pressure due to neutralizing the velocity of the gas passing through the manifold of the Curtiss OXX-2 engine.

The incoming gas entering the cylinder is brought to rest by striking against the piston head which has stopped at the end of the stroke. The inertia effect of the gas coming in at high velocity and striking the piston head builds up pressure. The effect is similar to the pressure built up on a sail due to the velocity of the wind striking against it. This building up of pressure in the cylinder at the end of the stroke is advantageous, as it increases the weight of charge in the cylinder.

2. *Method of Solution.*

(*a*) $$V = \sqrt{2gh},$$

where,

V = velocity of mixture in manifold in ft. per sec. (from Prob. 7)

g = acceleration of gravity = 32.2 ft. per sec. per sec.

h = pressure in ft.

(*b*) Transposing, $$h = \frac{V^2}{2g}.$$

(*c*) $$p = \frac{h \times d}{144}$$

where

p = pressure in lb. per sq. in.

d = weight of 1 cu. ft. of air at sea level and 32° F.

144 = number of sq. in. in 1 sq. ft.

3. *Known Values.*

V = 128 ft. per sec. (from Prob. 7).

g = 32.2 ft. per sec. per sec.

d = .0807 lb. per cu. ft.

4. *Solution.*

$$h = \frac{(128)^2}{2 \times 32.2} = 255 \text{ ft.}$$

$$p = \frac{255 \times .0807}{144} = .143 \text{ lb. per sq. in.}$$

235. Prob. IX. Pressure Depression at Fuel Nozzle. 1. *Statement.* Calculate the pressure depression at the fuel nozzle from the velocity of air passing through the contracted area of the carburetor on Curtiss OXX-2 engine.

2. *Method of Solution.* The quantity of charge passing through the contracted area of the carburetor is the same as that which goes through the intake manifold, and the value of Q found in problem VII can be used.

(*a*) $$V = \frac{Q}{a}$$

where,

Q = quantity of charge in cu. ft. per sec.

a = area of contracted section of carburetor in sq. ft.

V = velocity in ft. per sec.

(b) $$h = \frac{V^2}{2g}$$

where h = pressure head in ft.
g = acceleration of gravity.

(c) $$p = \frac{h \times d}{144},$$

where p = pressure depression in lb. per sq. in.
d = weight of 1 cu. ft. of air at sea level and 32° F
144 = number of sq. in. in 1 sq. ft.

3. *Known Values.*

Q = 1.71 cu. ft. per sec. (from Prob. I).

a = area of $\frac{29}{32}$ in. circle = .00448 sq. ft.

g = 32.2 ft. per sec. per sec.

d = .0807 lb. per cu. ft.

4. *Solution.*

$$V = \frac{1.71}{.00448} = 382 \text{ ft. per sec.}$$

$$h = \frac{(382)^2}{2 \times 32.2} = 2{,}260 \text{ ft.}$$

$$p = \frac{(2{,}260 \times .0807)}{144} = 1.26 \text{ lb. per sq. in.}$$

This is the measure of the pressure depression at the fuel nozzle. The pressure at the nozzle is lower than the atmospheric pressure by this amount. It is really a measure of the suction on the jet.

236. Prob. X. Effect of Altitude on Specific Weight and Mixture.

1. *Statement.*

Tabulate altitude vs. pressure data and plot curve.

Tabulate altitude vs. specific weight and plot curve.

Calculate the effect of altitude on mixture proportion, assuming no change in carburetor adjustment. Solve for Curtiss OXX-2.

2. *Method of Solution.*

From Table XXXII plot curve on Table XXXIV, and from Table XXXIII plot curve on Table XXXV.

Pressure of the air due to its velocity past the fuel jets varies as the specific weight of air.

Velocity of the gasoline through the jet varies as the square root of the pressure drop of the air and hence as the square root of the specific weight of the air.

That is: Air velocity varies as the specific weight of air.

Gasoline velocity varies as the $\sqrt{\text{specific weight}}$ of air.

And: $$\frac{\text{Gasoline velocity}}{\text{Air velocity}} \text{ or } \frac{\sqrt{\text{specific weight of air}}}{\text{specific weight of air}} = \text{ratio of gasoline to air.}$$

(Ratio of gasoline to air) − 1 = excess gasoline.

3. *Known Values.*

The specific weight of air at any altitude can be secured from Table XXXV.

4. *Solution.*

Find excess gasoline at 10,000 ft. altitude.

$$\text{Specific weight of air at 10,000 ft.} = .7375$$
$$\text{Square root of specific weight} = .86$$
$$\frac{.86}{.7375} = 1.17.$$
$$1.17 - 1 = 0.17, \text{ or 17 per cent. excess gasoline.}$$

At 20,000 ft.

$$\text{Specific weight of air} = .525$$
$$\text{Square root of specific weight} = .725$$
$$\frac{.725}{.525} = 1.38.$$
$$1.38 - 1 = .38, \text{ or 38 per cent. excess gasoline.}$$

At 30,000 ft.

$$\text{Specific weight of air} = .375$$
$$\text{Square root of specific weight} = .613$$
$$\frac{.613}{.375} = 1.625$$
$$1.625 - 1 = .625, \text{ or 62.5 per cent. excess gasoline.}$$

237. Prob. XI. Effect of Altitude on Brake Horsepower. 1. *Statement.* Calculate the effect of altitude on brake horsepower. Solve for Curtiss OXX-2.

2. *Method of Solution.*

$$\text{Indicated hp.} = \frac{\text{brake hp.}}{\text{mech. effy.}}$$
$$\text{Indicated hp.} - \text{brake hp.} = \text{friction hp.}$$

Indicated hp. at any altitude = indicated hp. at sea level times specific weight of air at the desired altitude. Brake hp. at this altitude equals indicated hp. at this altitude minus friction hp. at sea level.

3. *Known Values.*

$$\text{Brake hp.} = 100$$
$$\text{Mech. effy.} = 85 \text{ per cent.}$$

Specific weight of air from curve.

4. *Solution.*

$$\text{Indicated hp. at sea level} = \frac{100}{.85} = 117.5.$$
$$\text{Friction hp.} = 117.5 - 100 = 17.5.$$

At 10,000 ft.

$$\text{Indicated hp.} = 117.5 \times .7375 = 86.3$$
$$\text{Brake hp.} = 86.3 - 17.5 = 68.8$$

At 20,000 ft.

$$\text{Indicated hp.} = 117.5 \times .525 = 61.4$$
$$\text{Brake hp.} = 61.4 - 17.5 = 43.9$$

In this problem the speed of the engine is assumed constant at all altitudes. The friction horsepower will therefore remain constant irrespective of altitude.

238. Prob. XII. Inertia Forces. 1. *Statement.* Calculate the inertia force at inner and outer centers. Solve for Curtiss OXX-2 engine.

2. *Method of Solution.*

$$F_i = \frac{W}{g} \times \frac{4\pi^2 \times N^2}{3{,}600} \times R \times \left(1 + \frac{1}{n}\right)$$
$$F_o = \frac{W}{g} \times \frac{4\pi^2 \times N^2}{3{,}600} \times R \times \left(1 - \frac{1}{n}\right)$$

where,
F_i = force at inner center.
F_o = force at outer center.
W = weight of reciprocating parts in lb.
N = rated r.p.m.
g = acceleration due to gravity.
R = radius of crank in ft.
n = ratio $\dfrac{\text{length of connecting rod between centers}}{\text{crank radius}}$.

3. *Known Values.*

W = 3.75 lb.
N = 1,250 r.p.m.
g = 32.2 ft. per sec. per sec.
R = 2.5 in. = .208 ft.

$$n = \frac{8.25}{2.5} = 3.3.$$

4. *Solution.*

$$F_i = \frac{3.75}{32.2} \times \frac{4\pi^2 \times (1{,}250)^2}{3{,}600} \times .208 \times \left(1 + \frac{1}{3.3}\right).$$

Solving, $F_i = 542$ lb.

$$F_o = \frac{3.75}{32.2} \times \frac{4\pi^2 \times (1{,}250)^2}{3{,}600} \times .208 \times \left(1 - \frac{1}{3.3}\right)$$

Solving, $F_o = 288$ lb.

The difference in force at the outer and inner centers causes an unbalancing. It is this difference that causes vibration in a reciprocating engine. It cannot be balanced. The longer the connecting rods of an

engine, the greater is the value of n and the more nearly equal F_i and F_o become, hence decreasing the vibration. If the connecting rod is made of infinite length F_i and F_o are equal and the engine would be in perfect balance.

Rods are made short in aircraft engines to cut down heights of engines and head resistance.

239. Prob. XIII. Speed at Which Inertia Force Equals Maximum Gas Force. 1. *Statement.* Calculate at what speed the inertia force equals the maximum gas force.

2. *Method of Solution.*

From Prob. XII,
$$F_i = \frac{W}{g} \times \frac{4\pi^2 \times N^2}{3{,}600} \times R \times \left(1 + \frac{1}{n}\right)$$

From this equation,
$$N = \sqrt{\frac{F \times g \times 3{,}600}{W \times 4\pi^2 \times R \times \left(1 + \frac{1}{n}\right)}}$$

The symbols are the same as in Prob. XII.

F = maximum gas force = maximum gas pressure times area of piston.

3. *Known Values.* Area of piston = 14.19 sq. in.

From Prob. V, maximum gas pressure = 480 lb. per sq. in.

Remaining values are the same as in Prob. XII.

4. *Solution.*

$$N = \sqrt{\frac{480 \times 14.19 \times 32.2 \times 3{,}600}{3.75 \times 4 \times 9.9 \times .208 \times 1.303}}$$

$$N = 4{,}430 \text{ r.p.m.}$$

This problem is of no practical value, as various values are assumed which cannot be obtained in actual practice. It is assumed that the volumetric efficiency is constant with increased speed, while as a matter of fact, the efficiency decreases with increased speed. The only value of this problem is to show what magnitude the inertia force may reach.

240. Prob. XIV. Diagram Factor. 1. *Statement.* Tabulate the data of maximum theoretical efficiency compared with compression pressure. Calculate the diagram factor and plot curve of maximum efficiency vs. compression pressure.

2. *Method of Solution.* From Table IX plot curve on Table XXXVII.

$$\frac{\text{Thermal effy. calculated on brake hp.}}{\text{Mech. effy.}} = \text{Indicated thermal effy.}$$

$$\frac{\text{Indicated thermal effy.}}{\text{Maximum theoretical effy.}} = \text{diagram factor.}$$

3. *Known Values.* Curtiss OXX-2.

From Prob. II, thermal effy. on b.hp. = 19.35 per cent.

Mech. effy. = 85 per cent.

From Table XXXVII, maximum theoretical effy. for 90 lb. compression pressure = 39 per cent.

4. *Solution.*

$$\text{Indicated thermal effy.} = \frac{19.35}{.85} = 22.8.$$

$$\text{Diagram factor} = \frac{22.8}{39.0} = .584 \text{ or } 58.4 \text{ per cent.}$$

The diagram factor shows how nearly the engine approaches the ideal engine in efficiency.

The following Table XXXVII gives a summary of all the data of the six engines used in this subject with all known values and calculated answers.

TABLE XXVIII.—PRESSURE VS. VOLUME AND TEMPERATURE

Pressure increase	Compression				Expansions	
	Volume decrease		Temperature increase			
	Min.	Max.	Min.	Max.	Pressure decrease	Volume increase
1.0	1.0	1.0	1.0	1.0	1.0	1.000
1.2	0.870	0.877	1.05	1.06	0.90	1.082
1.4	0.775	0.786	1.08	1.10	0.80	1.175
1.6	0.702	0.716	1.13	1.15	0.70	1.290
1.8	0.643	0.659	1.16	1.19	0.60	1.435
2.0	0.595	0.611	1.19	1.22	0.55	1.532
2.2	0.554	0.571	1.22	1.26	0.50	1.640
2.4	0.520	0.537	1.25	1.29	0.45	1.770
2.6	0.490	0.507	1.27	1.32	0.40	1.932
2.8	0.462	0.481	1.30	1.35	0.35	2.117
3.0	0.440	0.459	1.32	1.37	0.30	2.370
3.5	0.392	0.410	1.37	1.43	0.25	2.690
4.0	0.354	0.373	1.42	1.49	0.20	3.150
4.5	0.324	0.343	1.46	1.54	0.18	3.400
5.0	0.300	0.318	1.50	1.59	0.16	3.690
5.5	0.280	0.297	1.53	1.63	0.14	4.050
6.0	0.261	0.280	1.57	1.68	0.12	4.529
7.0	0.233	0.250	1.63	1.75	0.10	5.15
8.0	0.210	0.228	1.68	1.82		
9.0	0.193	0.210	1.73	1.88		
10.0	0.178	0.194	1.78	1.94		

TABLE XXIX.—THEORETICAL COMPRESSION CURVE

Compression curve

Curve 1. Prob. 5.

TABLE XXX.—THEORETICAL EXPANSION CURVE

Expansion curve

Curve *II* Prob. 5.

Table XXXI.—Compression Pressure vs. Compression and Expansion Ratios

Compression pressure, lb. per sq. in. (gage)	Compression ratio $= \dfrac{\text{average pressure}}{\text{initial pressure}}$	Expansion ratio $= \dfrac{\text{average pressure}}{\text{initial pressure}}$
60	2.17	0.421
70	2.34	0.401
80	2.40	0.367
90	2.53	0.350
100	2.62	0.332
110	2.73	0.317
120	2.80	0.302
130	2.87	0.288

Table XXXII.—Altitude vs. Pressure

Altitude-pressure table	
Ft.	Lb. per sq. in. (absolute)
0	14.7
3,280	13.05
6,560	11.50
9,840	10.15
13,120	8.92
16,400	7.81
19,680	6.81
22,960	5.92
26,240	5.15
29,520	4.45
32,800	3.83
36,080	3.29

Temperature drop—3.3° F. per 1,000 ft. altitude.

Table XXXIII.—Altitude vs. Specific Weight

Altitude, (ft.)	Specific weight
0	1.0000
5,000	0.8600
10,000	0.7375
15,000	0.6226
20,000	0.5250
25,000	0.4425
30,000	0.3750

Table XXXIV.—Altitude vs. Pressure Curve

Curve *III*. Prob. 10.

Table XXXV.—Altitude vs. Specific Weight Curve

Curve *IV*. Prob. 10.

TABLE XXXVI.—MAXIMUM EFFICIENCY FOR DIFFERENT COMPRESSION PRESSURES

Compression pressure (gage)	Maximum efficiency
40	28.4
50	31.2
60	33.7
70	35.9
80	37.6
90	39.0
100	40.3
110	41.6
120	42.6
130	43.7

TABLE XXXVII.—MAXIMUM EFFICIENCY CURVE FOR DIFFERENT COMPRESSION PRESSURES

TABLE XXXVIII.—DATA AND ANSWER SHEET

Engine	Gnome	Hispano-Suiza	Liberty Navy	Hall-Scot A-7	Curtiss V-2	Curtiss OXX-2
Number of cylinders	9	8	12	4	8	8
Bore (in.)	4.33	4.72	5	5	5	$4\frac{1}{4}$
Stroke (in.)	5.9	5.12	7	7	7	5
Brake hp	100	154	385	100	200	100
R.p.m.	1,200	1,500	1,650	1,400	1,400	1,250
Mechanical effy. (%)	75	85	85	85	85	85
Fuel consumption (lb. per hp.-hr.)	0.862	0.52	0.543	0.543	0.54	0.646
	62° Bé.	60° Bé.	62° Bé.	58° Bé.	62° Bé.	62° Bé.
Compression pressure (lb. per sq. in. gage)	90	90	110	100	90	90
Ratio $\frac{\text{Conn. rod length}}{\text{Crank length}}$	.....	3.55	3.43	3.14	3.3	3.3
Weight reciprocating parts (lb.)	.....	†3.6	†5.28	6.63	5.3	3.75
	....	3.66	5.47			
Number of inlet manifolds	.....	2	4	1	2	2
Diam. inlet manifold (in.)	.....	2	2	2	2	$1\frac{9}{16}$
Diam. contracted area of carburetor (in.)	.....	1.18	$1\frac{7}{16}$	1.22	$1\frac{11}{32}$	$\frac{29}{32}$
Brake M.e.p. (lb. per sq. in.)	84.5	113	112	103	103	112
Indicated m.e.p. (lb. per sq. in.)	112.5	133	132	121	121	132
Mean Piston Speed (ft. per min.)	1,180	1,280	1,925	1,633	1,633	1,040
Thermol Effy. (%.)	14.5	24.03	23.0	23.1	23.11	19.35
Rate of heat generation (B.t.u. per sq. in. of piston)	221	194	302	234	234	194
Clearance (%.) (minimum value of S)	29.2	29.2	25	27	29.2	29.2
Maximum explosion pressure (lb. per sq. in.)	426	485	540	480	452.8	480
Inlet manifold velocity (ft. per sec.)	.....	118	150	170	170	128
Pressure due to in. manifold velocity (lb. per sq. in.)	.....	0.121	0.195	0.251	0.251	0.143
Velocity through carburetor (ft. per sec.)	.....	342	291	456	377	382
Pressure depression at carburetor (lb. per sq. in.)	.....	1.02	0.736	1.8	1.23	1.26
Inertia forces—inner and outer centers (lb)	.....	432	1,920	1,700	1,340	542
	.....	770	1011	879	720	288
Speed at which inertia force equals maximum gas force (r.p.m.)	.....	4,980	3,880	3,300	3,600	4,430
Diagram factor (%)	49.5	72.4	65.0	67.5	69.8	58.4

* Plain End Conn. Rod.
† Forked End Conn. Rod.

PART TWO

LABORATORY WORK

CHAPTER VIII

AIRCRAFT ENGINE IGNITION, LABORATORY

Determination of Characteristics of Liberty Storage Battery

This experiment is conducted to determine the characteristics of the lead-plate storage battery used with the Liberty engine and to familiarize the student with the connections and precautions necessary to charge the cells from a direct-current power line. It is important that the following facts be accurately determined.

The internal resistance of the cells at various points of charge. This is important because of its relation to the amount of sulphate on the plates.

The relation between the specific gravity of the electrolyte and the amount of charge.

The proper method for determining the degree of charge.

The proper method of connecting to a direct-current power line for charging.

The relation between the battery voltage on closed-circuit and the discharge period. The data obtained from the test is to be plotted as a curve to show this.

The following apparatus is used in this experiment: battery, voltmeter, ammeter, shunts, hydrometer, thermometer, lamp bank, variable rheostat, switch and power line.

The *battery* used is a lead plate type of four cells, which furnishes a pressure of about 8 volts. It is specially designed for the Delco ignition system used on the Liberty engine.

The voltmeter is to measure the electrical pressure across the line. It can be compared to a pressure gage measuring the pressure in a water line. Most direct-current voltmeters are of the rotating-coil type. A permanent horseshoe magnet is incased in a wooden box. Between the poles of the magnet is a small coil carrying the pointer, the coil being sensitized from the power line. The movement of the coil is proportional to the current passing through it. Most voltmeters require .01 ampere to give a full-scale deflection. Then from Ohm's law it is found that the

meter resistance is 100 ohms per volt. $R = \frac{E}{I} = \frac{1}{.01} = 100$ ohms per volt.

From this it is evident that a single meter can be made to work on lines of varying voltages by adding the proper resistances. Most meters have more than one range, that is, they will register a full scale deflection with various voltages, as 3 and 150, the only change necessary being to add another resistance, which is done by connecting to the 150-volt terminal, instead of to the 3-volt terminal. See Fig. 394.

If the 150-volt range is used and the scale is graduated to 150, it is direct reading. But if the 3-volt range is used, when 3 volts are

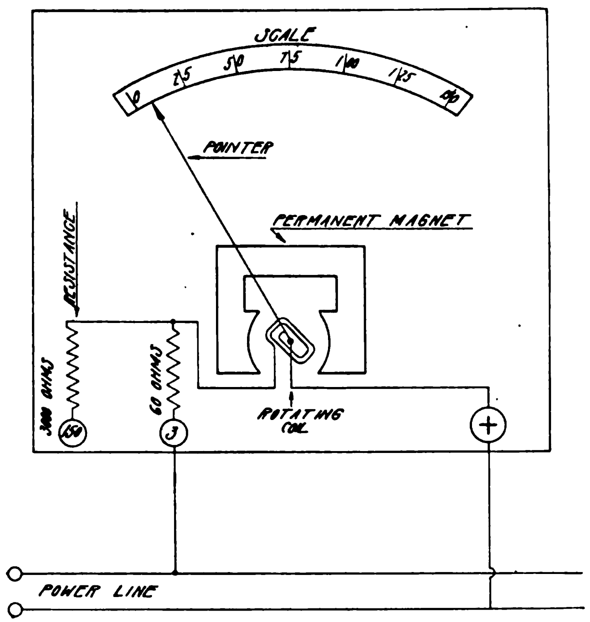

FIG. 394.—Direct-current voltmeter.

impressed across the meter, the scale deflection will be 150 which is 50 times too large. Thus, the reading must be divided by a constant to get a correct value. Therefore the constant is $\frac{\text{scale}}{\text{range}} = \frac{150}{3}$ or 50.

$$\text{True voltage} = \frac{\text{Observed voltage (scale deflection)}}{\text{Meter constant}}.$$

If the meter were used alone without the addition of any resistances, it would be called a millivoltmeter and have a resistance of .10 ohms. .001 volts would give a full scale deflection. Then, by adding a resistance of about 300 ohms, a full scale deflection would indicate 3 volts. $E = RI = 300 \times .01 = 3$. By adding a 15,000-ohm resistance the meter

would have a range of, $RI = 15{,}000 \times .01 = 150$, or 150 volts. See Fig. 84.

The *ammeter* is to measure the current flowing in the line and is connected in series with the line instead of in parallel with it as with the voltmeter. Its principle is based on Ohm's law. By measuring the pressure drop over a known resistance the current can be determined. Thus, if a pressure drop of .001 volts or 1 millivolt is measured across a resistance of .0002 ohms, the current flowing, as determined by Ohm's law, is 5 amp., Fig. 395.

$$I = \frac{E}{R} = \frac{.001}{.0002} = 5 \text{ amp.}$$

Thus, a single millivoltmeter, with a supply of various sized shunts or resistances, can be used to measure the current in any line. A shunt is usually made by mounting a strip of metal or piece of wire on a wooden base and connecting it to binding posts at each end. The shunts are numbered according to the current which they will carry with a pressure

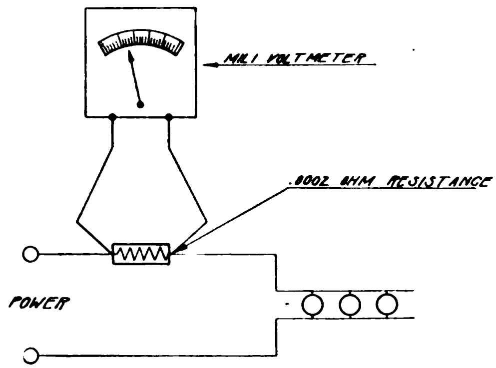

FIG. 395.—Ammeter and shunt.

drop of 1 millivolt. Thus, a 5-amp. shunt, when connected to a millivoltmeter will show a full scale deflection when five amperes are flowing.

Many ammeters do not require and cannot be used with external shunts. Such a meter is shown in Fig. 396. In this case the millivoltmeter and the shunts are encased in the same box. Such a meter may have several current ranges as 3 and 30 amp. In order to read the current accurately a constant must be used. Thus, with a scale graduated to 150 and a current range of 30 amperes, the constant is five. All observed readings must be divided by five to get the actual current.

$$\text{Constant} = \frac{\text{Scale}}{\text{Shunt}}.$$

$$\text{Actual current} = \frac{\text{Observed current (scale reading)}}{\text{Constant}}.$$

The advantage of an ammeter with external shunts over one with

internal shunts is one of space and price. One millivoltmeter with a dozen assorted shunts will usually do the work of several meters of the

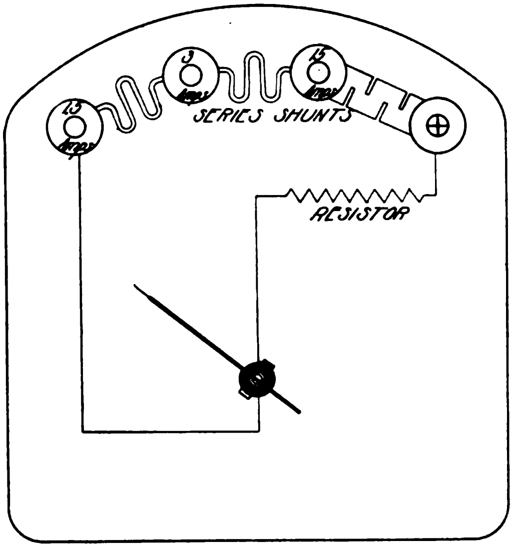

FIG. 396.—Multirange ammeter.

enclosed type, with a saving of several hundred per cent. in cost. Besides this the storage space is important as the meters are bulky.

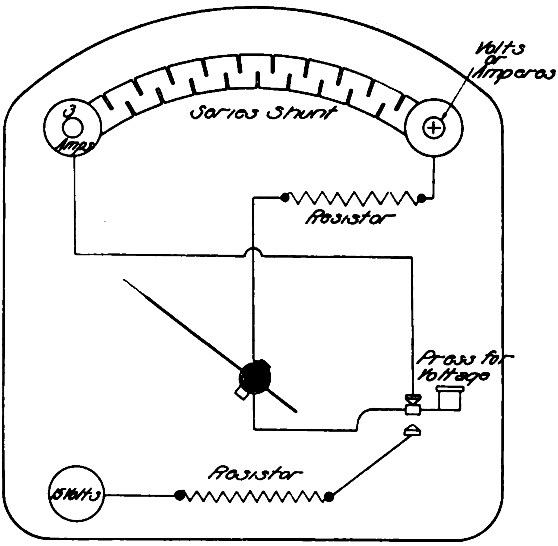

FIG. 397.—Volt-ammeter.

Besides those meters just described there are many combined volt-ammeters in use. The wiring of such a meter is shown in Fig. 397. It

consists of the ammeter with internal shunts, plus the resistance coil or coils and a switch *B*, whereby the shunts can be cut out and the resistance coil put in series with the rotating coil.

The *hydrometer* is used for determining the density of the electrolyte in the cells. The scale is calibrated directly in specific gravity multiplied by 1,000. Thus, a reading of 1,300 is actually $\frac{1,300}{1,000}$ or 1.3 specific gravity, which indicates that the electrolyte is $1\frac{3}{10}$ as heavy as an equal volume of water. Usually the hydrometer is of the syringe type, the float being encased in a glass cylinder of two or three times its diameter. The glass cylinder has a rubber tube at one end and a rubber bulb at the

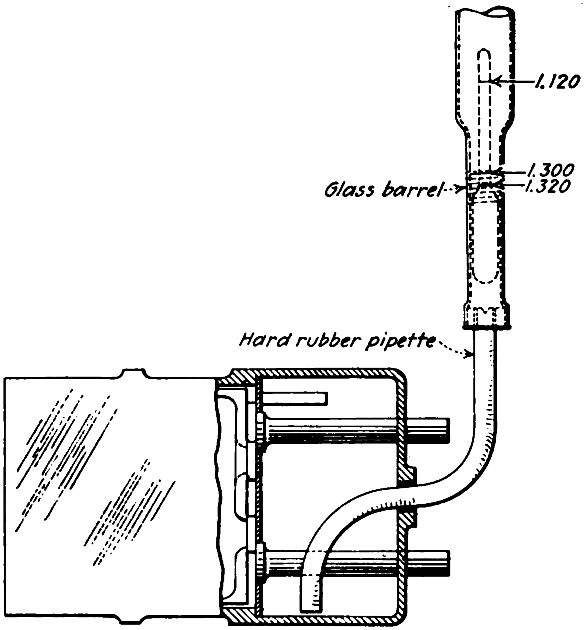

FIG. 398.—Taking hydrometer reading, Liberty battery.

other. The bulb is squeezed in the hand and released when the rubber tube is inserted in the electrolyte. When the bulb expands it draws the electrolyte into the barrel causing the float to rise. The syringe can be moved to the light to facilitate reading the scale. The design of the battery used with the Liberty engine makes it practically impossible to remove sufficient electrolyte with a straight tube attached to the syringe, therefore a crooked neck should be attached to the syringe and used as shown in Fig. 398.

A *thermometer* connection must be made for the temperature variation. The standard temperature for determining the electrolyte gravity is 80° F. If the temperature is three degrees over, one point must be added,

and if three degrees under, one point must be subtracted from the observed reading. Thus, if the specific gravity is 1,295 at 95° F. the specific gravity at 80° F. is 1,295 + $\frac{95-80}{3}$ or 1,300.

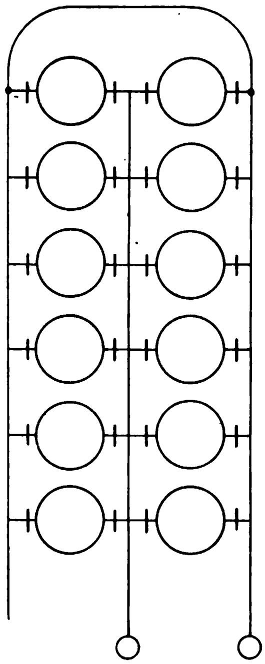

Fig. 399.—Lamp-bank.

For charging, a *lamp-bank* is used to vary the resistance and is placed in series with the line. Although the bank or set of lamps is in series with the line, the lamps are in parallel with each other. Fig. 399 shows a lamp-bank consisting of 12 lamps.

If the bank is used on a 110-volt line, all the lamps should be rated at about 110 volts. To vary the resistance, vary the quantity of lights being used. Since the current varies inversely as the resistance, the more lamps screwed in, the greater is the amount of current flowing. Thus, one 60-watt lamp will draw approximately .5 ampere. If it is desired to have more current flowing more lamps must be screwed in. It is customary to mount keyless sockets on a board to form the bank and then vary the number of lamps which will burn by screwing or unscrewing the bulb.

241. Battery on Discharge. To discharge the battery it is connected to a variable rheostat, as shown in Fig. 400. An ammeter is connected in the line and a voltmeter across the battery terminals. As the battery is to be discharged at 3 amperes, a 5-amp. shunt should be used.

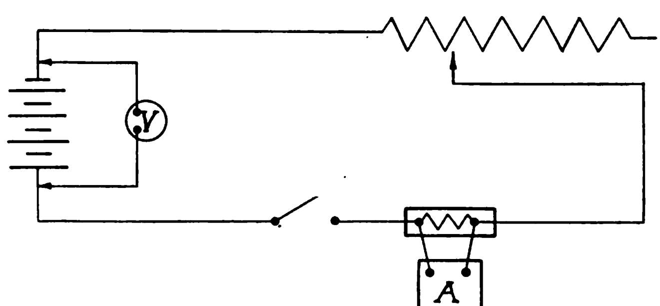

Fig. 400.—Connections for testing battery on discharge.

The 0 to 15 range of the voltmeter should be employed. Note the scale and range used on the voltmeter and obtain the meter constant. Record this on the log sheet. The customary method of denoting a

meter constant on the log is by preceding it with a division sign. Thus a scale of 150 divisions, and a 0 to 15-volt range gives a meter constant of 10 and is recorded as ÷ 10. Obtain the ammeter constant and record it properly.

Determine the specific gravity of the electrolyte by the hydrometer and record it on the log.

Close the *switch* and adjust the rheostat until the ammeter reads 3 amp., then open the switch.

Record the time and observed voltage in the proper column on the log, under Voltage, Open, Read. Close the switch and immediately record the voltage, this time under Voltage, Closed, Read. It is important to distinguish between open and closed voltage. The open voltage is the pressure on open-circuit or when the switch is open and no current is flowing through the battery. The closed voltage is the voltage on closed-circuit, or when the switch is closed and the battery receiving or delivering current.

Two minutes later read the closed voltage; open the switch and read the open voltage. Close the switch and repeat the readings every two minutes for 30 minutes, leaving the switch open after recording the last reading.

Record the hydrometer reading at the start and end of the test and correct for temperature change.

242. Battery on Charge. To charge the battery it should be connected in series with a lamp-bank to a 110-volt direct-current line, as shown in

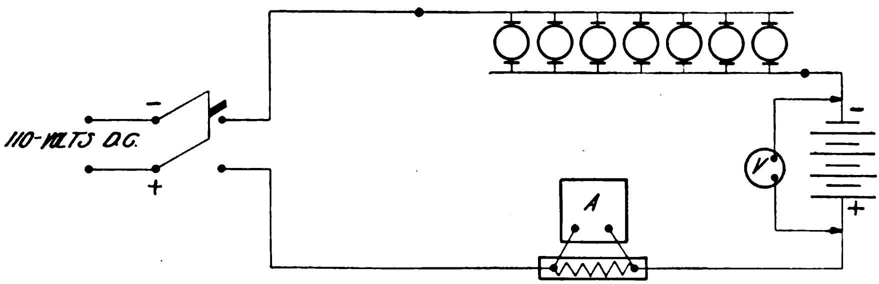

FIG. 401.—Connections for testing battery on charge.

Fig. 401. Care should be taken to see that the positive terminal of the battery is connected to the positive terminal of the line. Ammeter and voltmeter should be connected as before. As one lamp takes about 0.5 amperes the desired current of 3 amperes can be obtained by screwing in six lamps.

Observe the open voltage, close the switch and observe the closed voltage. Continue taking open and closed readings every 2 min. for 30 min. At the end of the charge period observe the hydrometer reading.

TABLE XXXIX.—DISCHARGE

Time of readings	Current I	Voltage: Open, E_o, ÷ 10 Read	Voltage: Open, E_o, True	Voltage: Closed, E_c, ÷ 10 Read	Voltage: Closed, E_c, True	Voltage drop across battery, $E_o - E_c = E$	Battery resistance, $R = \frac{E}{I}$	Hydrometer readings	Remarks
2:30	3	88.0	8.80	85.0	8.50	0.30	0.100	1305	
2:31	...	86.0	8.60	84.0	8.40	0.20	0.066		
2:32	...	85.8	8.58	84.0	8.40	0.18	0.060		
2:34	...	85.7	8.57	83.8	8.38	0.19	0.063		
2:36	...	85.6	8.56	83.7	8.37	0.19	0.063		
2:38	...	85.5	8.55	83.6	8.36	0.19	0.063		
2:40	...	85.4	8.54	83.4	8.34	0.20	0.066		
2:42	...	85.2	8.52	83.2	8.32	0.20	0.066		
2:44	...	85.0	8.50	83.0	8.30	0.20	0.066		
2:46	...	84.9	8.49	82.9	8.29	0.20	0.066		
2:48	...	84.8	8.48	82.8	8.28	0.20	0.066		
2:50	...	84.6	8.46	82.5	8.25	0.21	0.070	1300	
2:52	...	84.4	8.44	82.3	8.23	0.21	0.070		
2:54	...	84.2	8.42	82.1	8.21	0.21	0.070		
2:56	...	84.1	8.41	82.0	8.20	0.21	0.070		
2:58	...	83.9	8.39	81.8	8.18	0.21	0.070		
3:00	...	83.8	8.38	81.7	8.17	0.21	0.070		
3:02	...	83.8	8.38	81.6	8.16	0.22	0.073		
3:04	...	83.7	8.37	81.5	8.15	0.22	0.073		
3:06	...	83.6	8.36	81.5	8.15	0.21	0.070		
3:08	...	83.5	8.35	81.4	8.14	0.21	0.070		
3:10	...	83.4	8.34	81.3	8.13	0.21	0.070		
3:12	...	83.4	8.34	81.2	8.12	0.22	0.073		
3:14	...	83.3	8.33	81.1	8.11	0.22	0.073		
3:16	...	83.2	8.32	81.0	8.10	0.22	0.073		
3:18	...	83.2	8.32	81.0	8.10	0.22	0.073		
3:20	...	83.1	8.31	80.9	8.09	0.22	0.073	1280	

TABLE XL.—CHARGE

Time in minutes	Current I	Voltage				Voltage drop across battery, $E_o - E_c = E$	Battery resistance, $R = \frac{E}{I}$	Hydrometer readings	Remarks
		Open, E_o		Closed, E_c					
		÷ 10 Read	True	÷ 10 Read	True				
3:25	3	84.0	8.40	86.2	8.62	0.22	0.073	1280	
3:27	...	88.2	8.82	90.4	9.04	0.22	0.073		
3:29	...	88.9	8.89	91.0	9.10	0.21	0.070		
3:31	...	89.0	8.90	91.1	9.11	0.21	0.070		
3:33	...	89.4	8.94	91.5	9.15	0.21	0.070		
3:35	...	89.7	8.97	91.8	9.18	0.21	0.070		
3:37	...	89.9	8.99	92.0	9.20	0.21	0.070		
3:39	...	90.0	9.00	92.1	9.21	0.21	0.070		
3:41	...	90.2	9.02	92.2	9.22	0.20	0.066		
3:43	...	90.4	9.04	92.4	9.24	0.20	0.066		
3:45	...	90.7	9.07	92.7	9.27	0.20	0.066		
3:47	...	90.7	9.07	92.7	9.27	0.20	0.066		
3:49	...	91.0	9.10	93.0	9.30	0.20	0.066	1290	
3:51	...	91.2	9.12	93.2	9.32	0.20	0.066		
3:53	...	91.3	9.13	93.4	9.34	0.21	0.070		
3:55	...	91.6	9.16	93.8	9.38	0.22	0.073		
3:57	...	92.2	9.22	94.5	9.45	0.23	0.076		
3:59	...	92.6	9.26	94.9	9.49	0.23	0.076		
4:01	...	92.8	9.28	95.2	9.52	0.24	0.080		
4:03	...	93.4	9.34	95.8	9.58	0.24	0.080		
4:05	...	94.0	9.40	96.4	9.64	0.24	0.080		
4:07	...	94.6	9.46	97.2	9.72	0.26	0.086		
4:09	...	95.2	9.52	97.8	9.78	0.26	0.086		
4:11	...	95.5	9.55	98.3	9.83	0.28	0.093		
4:13	...	96.0	9.60	98.9	9.89	0.29	0.096		
4:15	...	96.4	9.64	99.4	9.94	0.30	0.100	1300	
6									

243. Calculations and Curves. Now that the desired amount of data has been secured, it is necessary to make computations in order to complete the experiment. All of the observed voltage readings must be divided by the meter constant, which in this case is 10, in order to obtain the true voltage. These true voltages should be recorded on the log sheet.

Next obtain the voltage drop across the cell. This is done by subtracting the true voltage on closed-circuit from the true voltage on open-circuit for the discharge period, and the open voltage from the closed while on charge. Record these properly on the log sheet.

By Ohm's law we can determine the cell resistance, thus $R = \frac{E}{I}$. For each reading divide the voltage drop across the cell by the current.

The following table shows a completed log sheet for both charge and discharge periods.

Plot a curve between closed voltage and time as shown in Fig. 402. From this we see that the voltage drops very rapidly for a short period of time after the switch is closed and then is nearly constant for a period of considerable length. If the discharge is continued for sufficient time to discharge the battery to the practical limit, it will be found that toward the end of the discharge the voltage again falls off rapidly. The reverse takes place during charge; the voltage rises rapidly, then is fairly constant for a period of considerable length but again rises rapidly as the cell nears the end of the charge period.

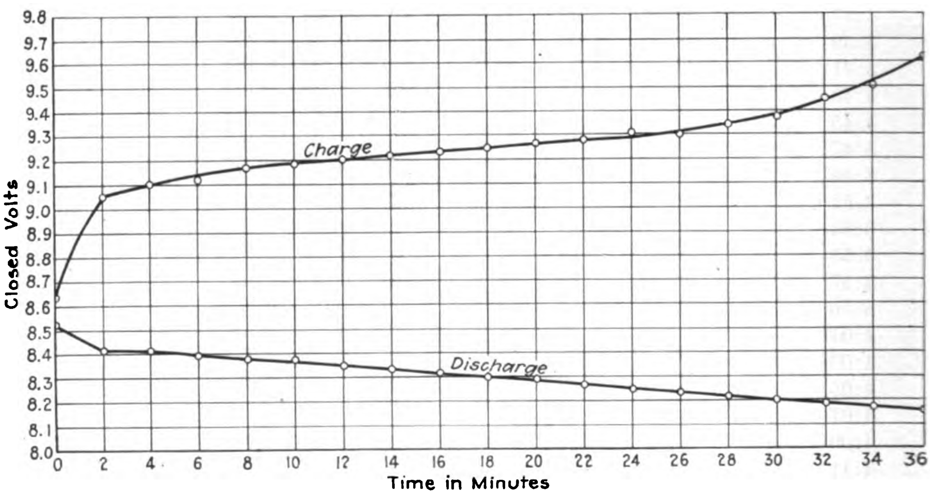

FIG. 402.—Curves of closed volts. vs. Time for charge and discharge.

During discharge the resistance of the cell rises, due to the formation of lead sulphate on the plates. In some cases however, the resistance may fall slightly at the beginning of the discharge and then continue to rise steadily during the remainder of the discharge. During charge, the resistance falls until near the end of charge when it may rise if the cell is allowed to gas.

Characteristics of Sulphated and Short-circuited Cells

244. Cells on Charge. Sulphation increases the resistance of a cell. This is due to the fact that lead sulphate is a non-conductor and hence practically no current can pass through that portion of the plate which is sulphated. The result is that a sulphate cell requires a higher voltage to charge it than a normal cell, or in other words the closed volts on charge are higher than normal. In a sulphated cell, due to the fact that

some of the sulphate ions cannot be driven back into the acid on charge but remain in the plates, the gravity of the electrolyte will not rise to its full charge value. Hence due to the lower density electrolyte, the open circuit voltage will also be somewhat lower than in a normal cell. The relation between open and closed volts will of course vary with the size and number of plates in the cell. Therefore in determining if a cell is sulphated, comparison must be made with a normal cell of the same type.

The effect of a short-circuit will vary considerably, depending on the nature of the short-circuit and the length of time that is has existed before the cell is tested.

The effect of a short-circuit is to discharge the cell continuously whether it is idle or in use. Due to the short-circuit, the internal resistance is lowered. The result will be that both the open and closed circuit voltages on charge will be lower than normal.

Typical readings of the open and closed voltages, gravity and resistance of good, short-circuited, and sulphated cells, are given in the following table. These tests were not made on a Liberty battery.

TABLE XLI.—CELLS ON CHARGE

Cells	Current, amperes	Closed voltage	Open voltage	Specific gravity	Internal resistance, ohms
Good cell	1	2.4	2.2	1,200	0.2
Short-circuited cell	1	0.6	0.5	1,200	0.1
Sulphated cell	1	2.9	2.1	1,150	0.8

245. Cells on Discharge. The effect of sulphation when the cell is discharging is to lower the closed volts, that is, due to the high resistance of the cell there is a high internal voltage drop on discharge.

In a short-circuited cell the closed volts on discharge is very low. In some cases it may even be zero. In the following table typical readings for good, short-circuited and sulphated cells are given.

TABLE XLII.—CELLS ON DISCHARGE

Cells	Current, amperes	Closed voltage	Open voltage	Specific gravity	Internal resistance, ohms
Good cell	1	2.0	2.2	1,200	0.2
Short-circuited cell	1	0.1	0.5	1,200	0.4
Sulphated cell	1	1.0	2.1	1,150	1.1

The apparent high resistance, given in this table, for the short-circuited cell is not a true indication of the condition. In reality the resistance of a short-circuited cell is lower than that of a normal cell. In this case, loading the battery probably changes the conditions inside

the cell in such a way as to decrease the resistance, with the result that the short-circuit current is increased causing a big drop in the terminal volts.

Disassembly and Assembly of Liberty Storage Battery

246. Disassembly. The batteries used in ignition work on the Liberty engine, namely the Willard and Exide, differ somewhat in construction.

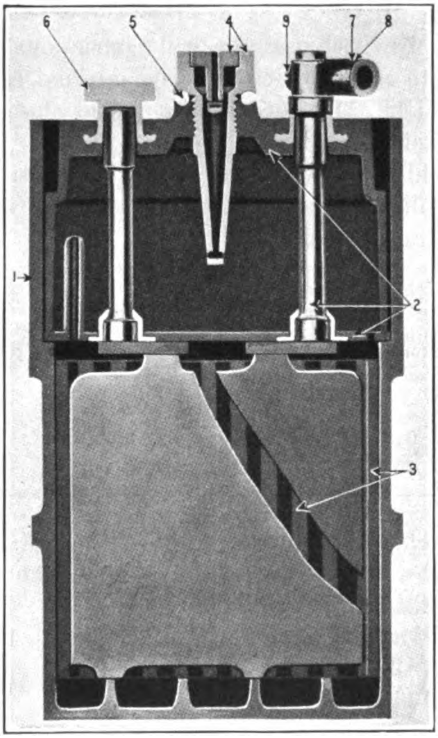

FIG. 403.—Vertical section of the Willard battery. Type SY-13.

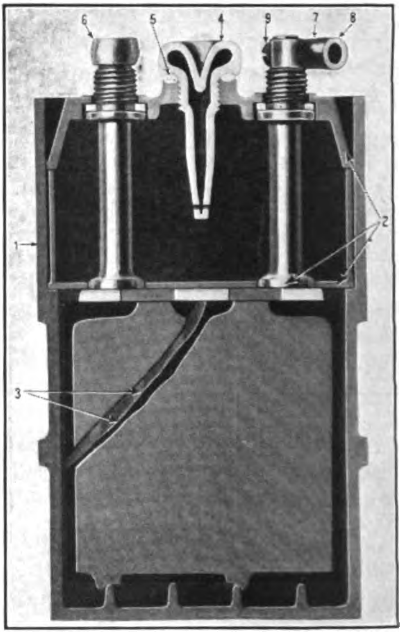

FIG. 404.—Vertical section of the Exide battery. Type 4-AC-7.

In the Willard an-acid tight connection between the cover and post is made by means of a lead collar, vulcanized into the hard rubber of the cover through which the post is inserted and the two burned together.

In the Exide the post has a shoulder on which rests a soft rubber washer and on this rests the cover which is held down securely by a hard-rubber lock nut.

The first operation in the disassembly of the Willard is the cutting off of the terminal post $3/16$ in. above the top of the cover. This can be done with carpenters snips or a hack saw. Fig. 405.

This operation on the Exide is accomplished by the removal of lock nuts.

The next operation is the removing of the top connectors. Carefully punch the centre of the post with a centre punch. In the Willard, with the use of a 3/8-in. drill and a carpenter's brace, drill a hole through each end of the top connector. Fig. 406.
Heat the center of the drilled holes slightly with a hydrogen flame and raise the connector from the base with a screw-driver, or similar tool. Care should be taken to see that the hole is drilled deep enough to show the seam between the center post and the cover insert sleeve.

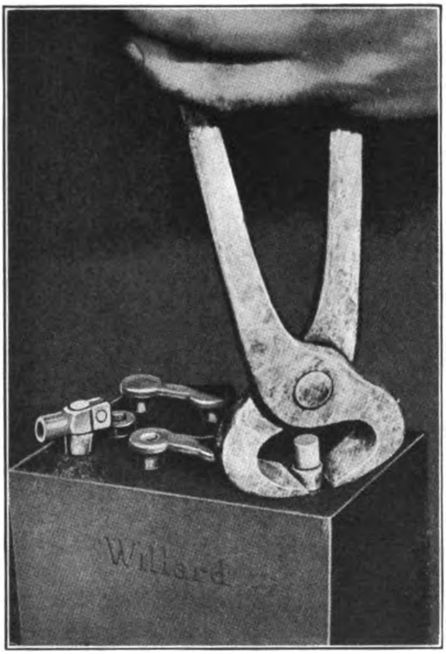

FIG. 405.—Cutting off terminal post.

On the Exide the connectors are drilled the same way, with a 1/4-in. drill.

Remove the sealing compound between the cover and jar with the aid of a heated blade 1/2 in. wide and 3/32 in. thick. Heat the cover slightly with a flame, steam, or by use of an oven. If flame is used care should be taken to remove vent plugs and blow out the gas to prevent an explosion. The sealing compound can now be easily removed and with the aid of a heated thin bladed putty knife the cover can be loosened from the jar. Next, in the Willard, replace the vent plugs and remove the cover by taking hold of plug with a pair of pliers, Fig. 409. Never grasp the insert sleeve with the pliers as it is easily crushed.

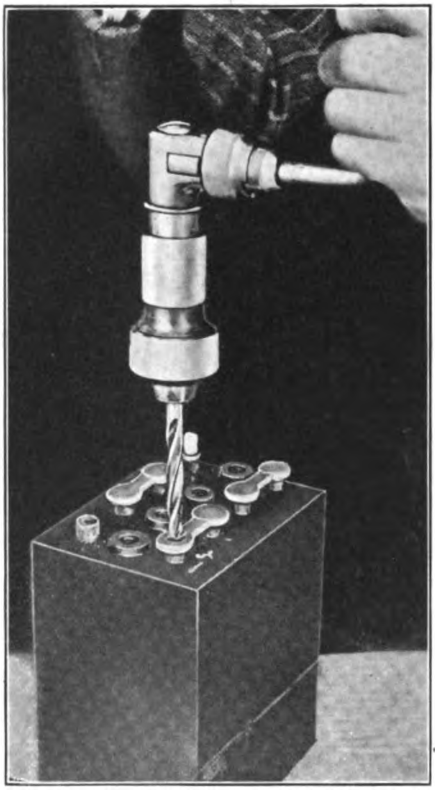

FIG. 406.—Drilling post.

FIG. 407.—Removing sealing compound.

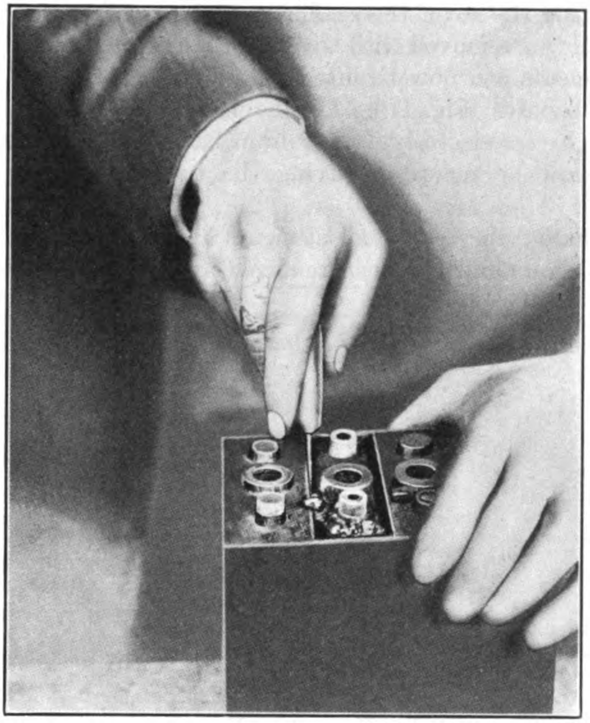

Fig. 408.—Loosening cover from jar.

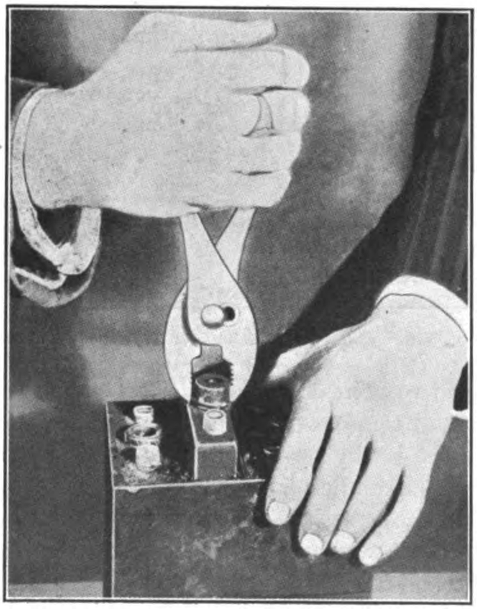

Fig. 409.—Removing cover from jar.

After removing the cover the sealing compound adhering to the side of the jar should be removed with the use of a hot blade.

The elements can now be lifted out by pulling evenly on each connecting strap post. Fig. 410. Let the elements rest on the sides of the jar so that the excess electrolyte may drain back into the jar. The baffle plate can now be removed leaving the two assembled groups with separators.

In the Exide, the cover and elements are removed together. After the sealing compound has been removed and the cover loosened grasp

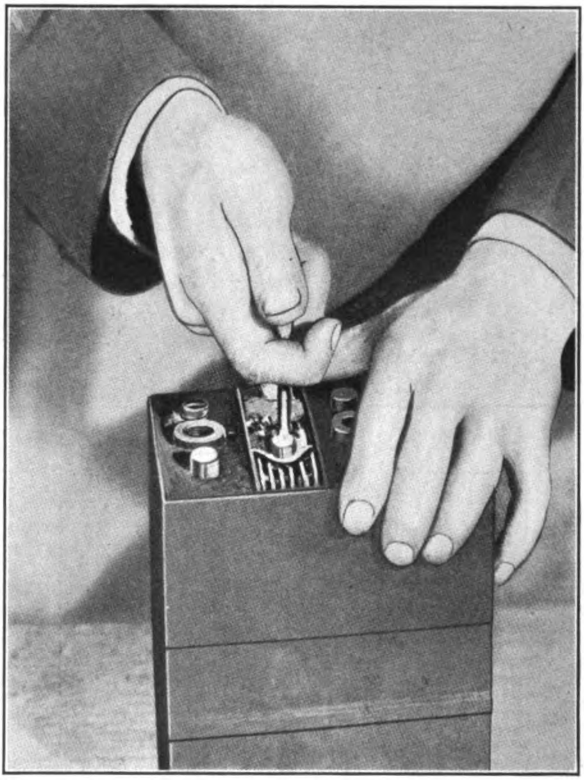

FIG. 410.—Removing the elements, Willard battery.

the two posts with two pairs of gas pliers, if necessary holding the battery between the feet and remove the elements, allowing the excess electrolyte to drain into the jar by resting the elements on the side.
The cover, spacer and baffle-plate can now be removed. Remove the hard rubber sealing knobs with a special wrench. This permits the cover, spacer and soft rubber washer to be removed. The baffle-plate should be heated slightly before removing to prevent breaking it when forcing it over the shoulder on the posts.

The groups can now be pulled apart by grasping the posts and working them back and forth. The electrolyte can now be removed from the jar.

247. Inspection of Elements. Examine the jar for cracks, breaks or flaws that might permit the electrolyte to leak out. All sediment should be washed from the jar. Posts should be examined to see if they are loose or in a bad condition. The positive plates should be carefully looked over for washing out of material, and other defects.

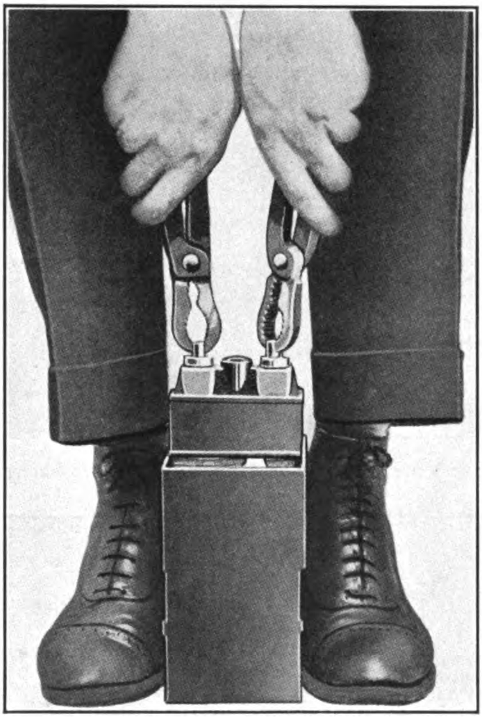

FIG. 411.—Removing the elements, Exide battery.

The negative plates are as a general rule in good condition; but they should be examined to see that the active material is soft and spongy and shows no results of sulphation or bulging from overcharging.

Separators should be examined for splits, perforations and mechanical strength. As a general rule, however, it will be found advisable to replace the separators when repairing the battery.

The electrolyte also should be replaced with some of known purity. In most cases the old electrolyte will contain some impurities.

248. Assembly. First assemble the groups with separators. Count the separators after assembling to see that none are missing, and that they extend evenly on both sides of the plates.

In the Exide, when replacing a combined wood and rubber separator, the ribbed side of the rubber should be against the wood, and the rubber against a positive plate.

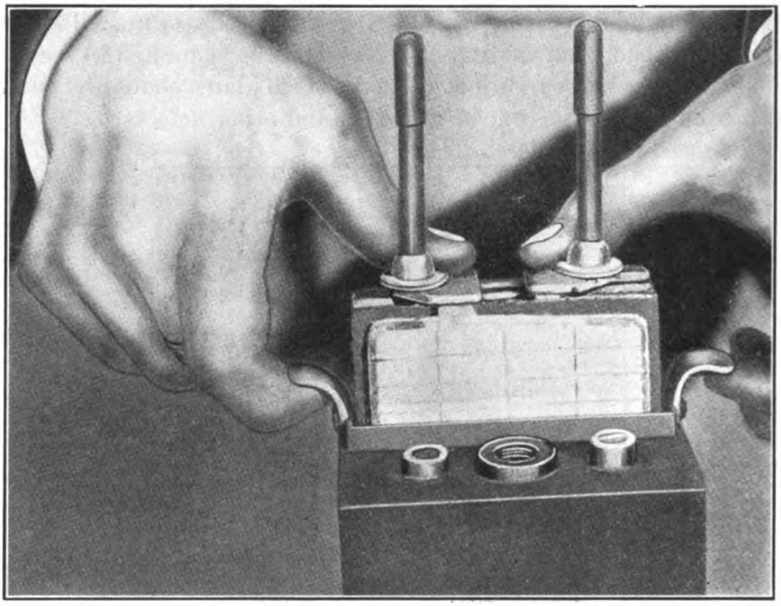

Fig. 412.—Replacing the elements—Willard battery.

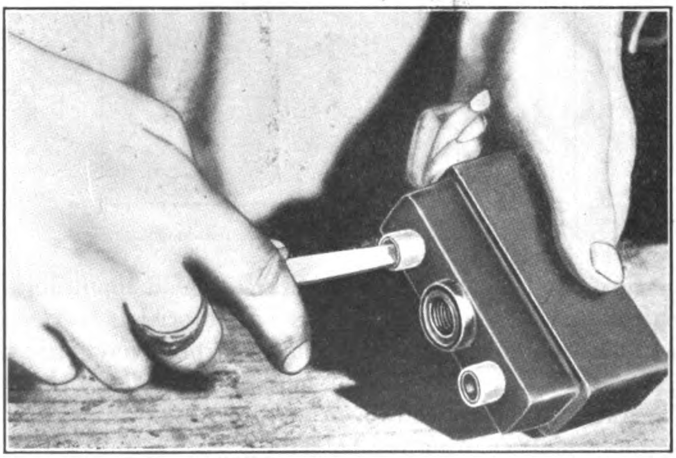

Fig. 413.—Scraping sleeves in cover

In the Willard, a special jig is used for inserting the group in the jar. The inside dimensions of the jig are the same as the inside dimensions of the lower part of the jar. The group is inserted as shown in Fig. 412.

Put the baffle-plate in place after seeing that the soft-rubber gaskets on which the plate rests, are in place. Scrape the inside and outside of

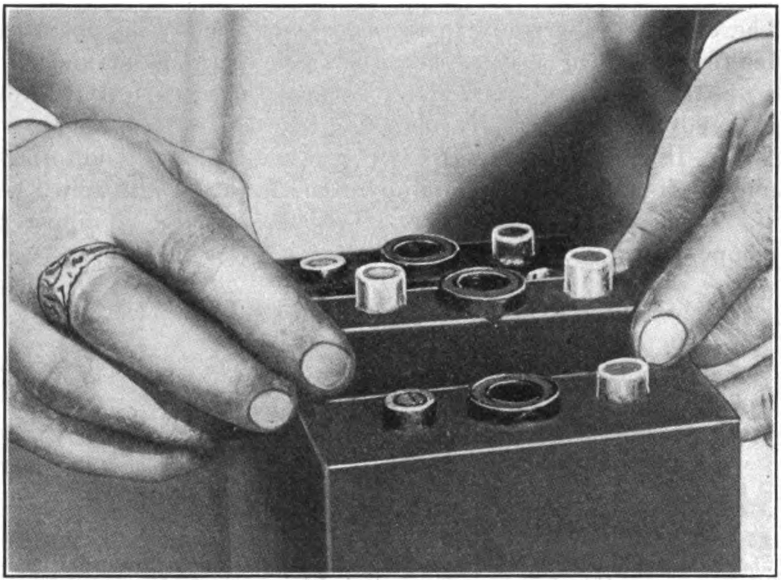

Fig. 414.—Replacing cover over connecting strap posts.

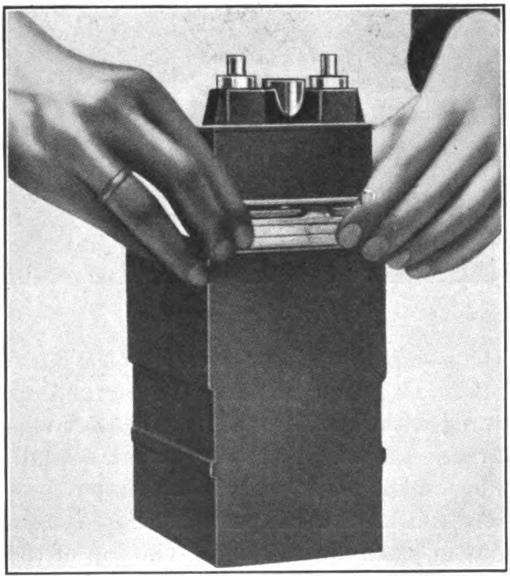

Fig. 415.—Replacing an element—Exide battery.

the lead sleeves in the cover, Fig. 413, and install the cover over connecting strap posts; Fig. 414.

In the Exide the baffle-plate, spacer and cover are assembled into a group and then the group is placed in the jar, being careful to clear the inside flanges. Fig. 415.

The cells are now ready to be sealed but before this operation is started the surfaces to be sealed should be wiped with ammonia and allowed to dry as otherwise the compound may not stick and a leak will result. Care should be taken with the compound in order to finish the assembly properly. It should be slowly heated until it is all in a liquid form with no lumps. If the compound is lumpy a poorly sealed battery will be the result. With special dipper, or regular sealing compound dipper, pour the compound between the cover and the jar. See Fig. 416.

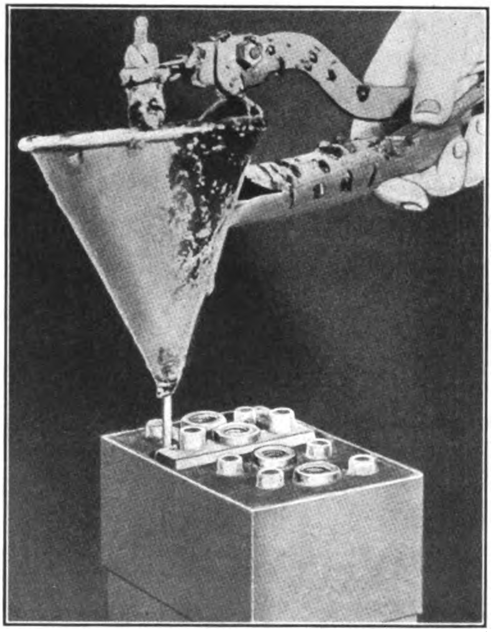

Fig. 416.—Sealing the cell.

On the Willard the inside post is now burned to the outside sleeve with a suitable flame. Before burning, all parts to be burned must be thoroughly cleansed by scraping with a knife or file. A copper clamp is applied to the post to be burned and with the battery tilted, a small stream of water is permitted to flow on the other end of the clamp.

The top connectors and tops of the posts are now thoroughly cleaned and the connectors put in place for burning. The top of the post should be slightly lower than the top of the connector to allow space for burning. A spring clamp should be used around the head of the connector to prevent the lead from running.

After all connections are burned out, the posts are built up, using post

builders for this purpose. Fig. 419. The post builders have to be of two sizes, one for the positive and one for the negative posts.

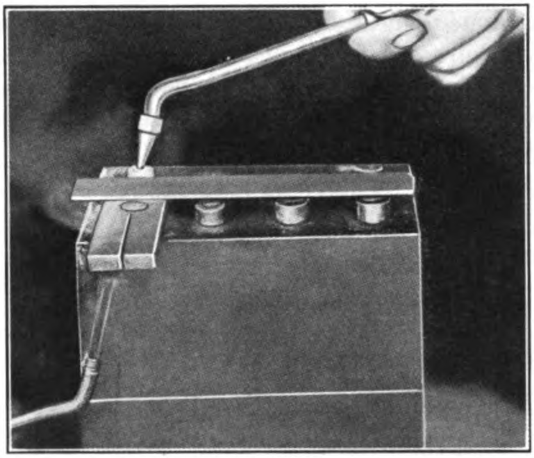

FIG. 417.—Burning post to sleeve—Willard battery.

The heat for lead burning may be obtained from electrically heated carbon or from the burning of the mixture of two gases. In either case a special outfit is necessary, but the gas is most commonly used.

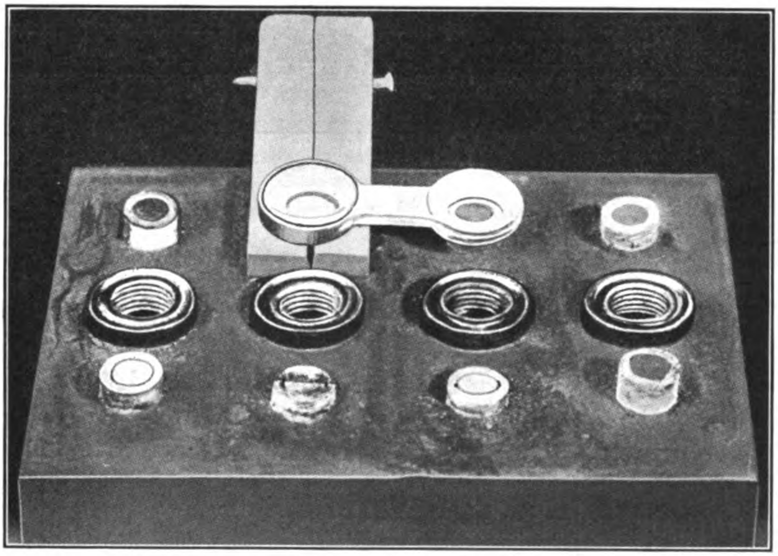

FIG. 418.—Preparing connector for burning.

The combinations of gases which may be used in burning are: artificial illumination gas and oxygen, natural illuminating gas and oxygen,

artificial illuminating gas and air, hydrogen gas and air. In all cases the gas must be under some pressure and a mixing chamber with a burning tip must be used. If oxygen is used a special valve is required and the mixing must be done right at the burning tip which necessitates the mixing chamber and burning tip being combined in one piece.

In order to avoid the possibility of an explosion, when doing lead burning the following precautions should be observed. Remove the vent plugs and blow into the vents to remove any gas which may be in the cells. Replace the vent plugs and cover the battery, excepting the part on which the burning operation is to be performed, with a cloth thoroughly

FIG. 419.—Building up post.

wet with water. The cloth should be pressed down upon the vents of the cells.

Characteristics of Liberty Generator Operating With and Without Voltage Regulator

249. Generator Operation with Regulator. *Determination of Effect of Speed upon Field Current Battery Charging Current and Generator Voltage, Battery in Circuit.* The object of this test is to determine the normal operating characteristics of the Liberty generator when connected to the battery and the voltage regulator.

The generator is first placed in a suitable rack so that it can be driven by means of a variable-speed motor. The instruments needed for the test are, one multiscale direct-current voltmeter, two direct-current ammeters, one tachometer, one 5-amp. and one 10-amp. shunt. This apparatus is to be connected as shown in Fig. 420.

After the apparatus has been properly connected the squad leader will assign each man a specific job as follows: reading generator terminal, voltage, reading battery charging current, reading generator field current,

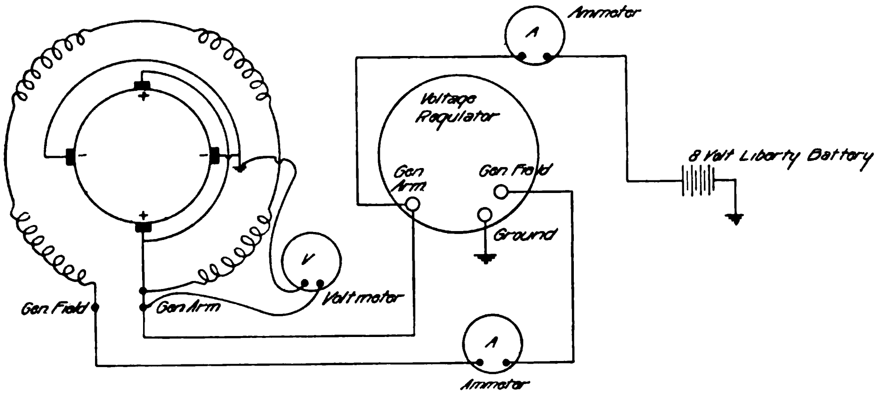

FIG. 420.—Wiring diagram of Liberty generator, operating with voltage regulator.

controlling and reading generator speed, and recording the readings in the log. The log-keeper will first make up a log-sheet, recording meter constants.

GENERATOR SPEED R.P.M.	GENERATOR TERMINAL VOLT		GEN. CHARGING CURRENT		GEN. FIELD CURRENT	
	AS READ	TRUE	AS READ	TRUE	AS READ	TRUE
	K= ÷2		K= ÷20		K= ÷10	
700	16.8	8.4	-4.0	-0.5	24.0	2.4
900	17.4	8.7	+18.0	+0.9	21.0	2.1
			K= ÷2			
1100	18.0	9.0	4.2	2.1	18.0	1.8
					K= ÷20	
1300	18.4	9.2	6.4	3.2	28.0	1.4
1500	18.8	9.4	7.8	3.9	24.0	1.2
1700	19.2	9.6	8.4	4.2	22.0	1.1
1900	19.4	9.7	9.0	4.5	20.0	1.0
2100	19.6	9.8	9.4	4.7	18.0	0.9
2300	19.6	9.8	9.8	4.9	17.0	0.9
2500	19.6	9.8	10.2	5.1	16.0	0.8
2700	19.8	9.9	10.6	5.3	15.5	0.8
3000	19.8	9.9	11.2	5.6	15.0	0.75

FIG. 421.—Typical log of results of speed vs. Terminal voltage, charging current and field current, Liberty generator operating with voltage regulator and battery.

After the log-sheet has been prepared and the apparatus properly connected the man controlling the driving motor will start this machine and bring the generator speed to about 700 r.p.m. Each instrument

man watches his instrument, and notes the reading as soon as the tachometer man signals that the speed of the generator is exactly 700 r.p.m. The men will give their readings to the log-keeper in some convenient order, which is to be followed throughout the remainder of the tests.

No attempt should be made to correct the meter readings to their true value in volts or amperes. Only division deflections are to be recorded by the log-keeper. It will be assumed that the meters record correctly, which is the case within a very small limit of error. Readings are to be taken in the same manner at intervals of 200 r.p.m. up to 3,000 r.p.m.

A typical log of the results of this test is shown in Fig. 421.

Determination of Effect to Speed upon Field Current and Generator Terminal Voltage, Battery Disconnected. The connections for this test are the

GENERATOR SPEED R.P.M.	GENERATOR TERMINAL VOLTS		GENERATOR FIELD CURRENT	
	AS READ	TRUE	AS READ	TRUE
	K= ÷2		K= ÷10	
700	10.8	5.4	18.0	1.8
900	15.2	7.6	17.0	1.7
1100	18.0	9.0	15.5	1.55
			K= ÷20	
1300	19.0	9.5	26.0	1.3
1500	19.4	9.7	22.0	1.1
1700	19.6	9.8	20.0	1.0
1900	19.8	9.9	17.0	0.85
2100	20.0	10.0	16.0	0.80
2300	20.0	10.0	14.0	0.70
2500	20.2	10.1	13.0	0.65
2700	20.3	10.2	12.0	0.60
3000	20.4	10.2	11.0	0.55

FIG. 422.—Typical log of results of speed vs. Terminal voltage and field current, Liberty generator operating with voltage regulator alone.

same as for the previous test except that the battery and the line ammeter are disconnected from the "Gen. Armature" terminal of the voltage regulator and a 2-amp. shunt is used in the field instead of a 5-amp. shunt. The procedure is the same as in the preceding test, readings being taken at speed intervals of 200 r.p.m. from 700 r.p.m. to 300 r.p.m. A typical log of the results is shown in Fig. 422.

Curves of Results. These curves are not plotted until the entire tests have been completed, including the two runs with the generator operating without the voltage regulator.

After the tests have been completed all readings are to be corrected for meter constants and the curves plotted as shown in Fig. 423. All curves are plotted against generator speeds as abscissæ.

The speed-voltage curve for the generator with regulator and battery connected is seen to rise slightly up to about 1,200 r.p.m. and then becomes practically a straight horizontal line. It is seen that the maximum voltage change is small over the entire speed range, and much less than would be obtained in the case of a differentially-wound compound generator or third-brush generator. The curve of the generator terminal voltage against speed with the battery disconnected is seen to have a much greater variation, but the voltage at no point reaches an abnormal value as would be the case in the differentially wound compound generator or third-brush generator.

By referring to the typical logs it will be seen that as the speed is increased, the field current falls. This must necessarily be the case since

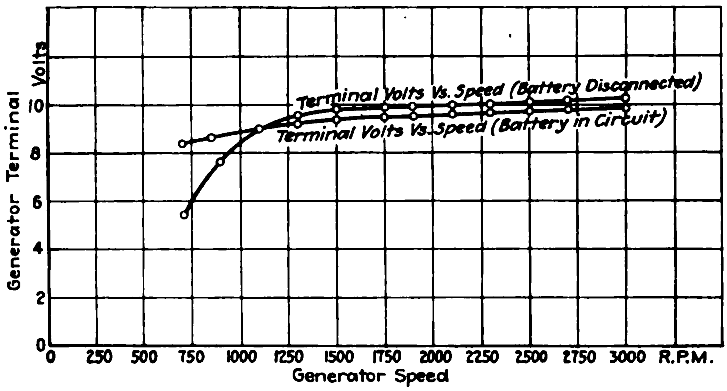

FIG. 423.—Characteristic curves of Liberty generator operating with regulator.

the voltage is very nearly constant at all speeds. The drop in field current is due to the action of the regulator which cuts resistance in and out of the field circuit as explained in the lecture. The greater the speed of the generator the faster the regulator armature vibrates. The effect is that the resistance remains in series with the shunt field a greater length of time as the generator speed increases. If readings had been taken at speeds below the speed at which the regulator begins to operate, it would have been found that the shunt field current actually increases with increased generator speed up to the point where the regulator begins to operate.

250. Generator Operation Without Regulator. *Effect of Field Current on Magnitude of Generator Terminal Voltage at Constant Speed, Generator Field Separately Excited.* This test consists of a constant speed run on the generator without load, the shunt field being separately excited. The field current of the generator, supplied by an 8-volt Liberty storage battery, is controlled by means of a variable drum rheostat in series with the field circuit. A multiscale direct-current voltmeter will be used to

measure generator terminal voltage and a direct-current ammeter and 2-amp. shunt to measure field current. Speed will be determined by means of a tachometer as in the preceding tests.

The object of the test is to obtain the relation between generator terminal volts and field amperes at constant speed. The connections for this test are to be made as shown in Fig. 424.

After the apparatus has been properly connected, the squad leader will assign each man a specific job as follows: reading the generator terminal voltage, reading field current, reading generator speed, controlling the speed of the generator by means of the variable speed motor and recording the readings in the log. The log-keeper will make up a log-sheet as shown in Fig. 425.

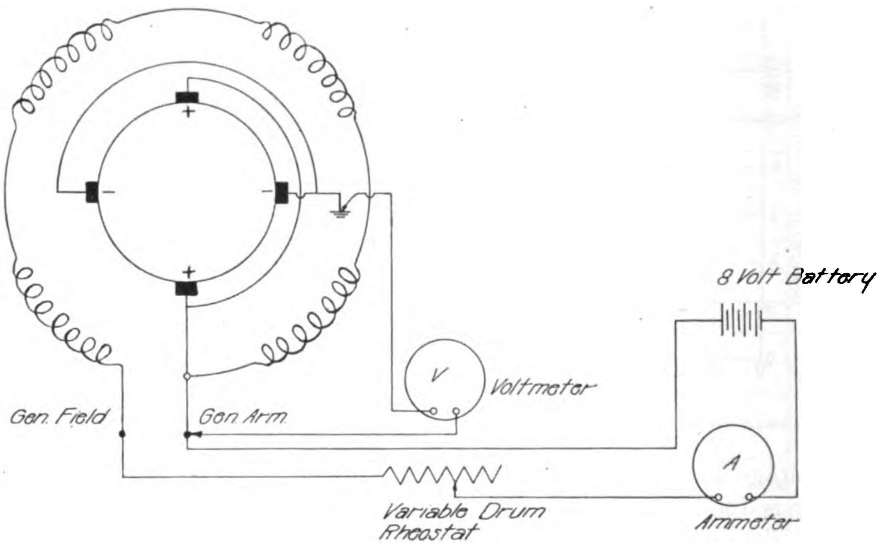

FIG. 424.—Wiring diagram of the Liberty generator operating without voltage regulator.

The man operating the driving motor will now start this machine and bring the generator speed up to about 2,500 r.p.m. It may be found advisable to have the man reading the tachometer, control the speed of the driving motor. For the first reading the field current should be adjusted to 1.75 amp. As soon as the man at the tachometer signals that the generator speed is exactly 2,500 r.p.m. the men note the instrument readings and give them to the log-keeper in the proper order. Only meter deflections in divisions are recorded. It is not essential that the field current value be set exactly, but whatever the setting may be, it should be read as accurately as possible. Similar sets of readings are taken at the same speed for field current values down to zero field current in steps of 0.25 amp.

A typical log of results is shown in Fig. 425.

Effect of Speed on Terminal Voltage, Field Current Constant at Normal Value. The connections for this test are the same as in the preceding test. The field current is set at 1.75 amp. The man controlling the speed of

GENERATOR SPEED R.P.M.	GENERATOR TERMINAL VOLTS		GENERATOR FIELD CURRENT	
	AS READ	TRUE	AS READ	TRUE
	K = X5		K = ÷10	
2500	4.6	23.0	17.5	1.75
			K = ÷20	
2500	4.2	21.0	30.0	1.50
2500	3.7	18.5	25.0	1.25
2500	3.1	15.5	20.0	1.00
	K = ÷2			
2500	24.4	12.2	15.0	.75
2500	17.2	8.6	10.0	.50
2500	11.2	5.6	5.0	.25
2500	8.0	4.0	0	0

FIG. 425.—Typical log of results of field current vs. terminal voltage Liberty generator separately excited without voltage regulator at constant speed.

the driving motor varies the speed of the generator from 700 r.p.m. to about 3,000 r.p.m. in steps of about 300 revolutions. As the speed approaches the correct value for a reading it is to be increased very slowly,

GENERATOR SPEED R.P.M.	GENERATOR TERMINAL VOLTS		GENERATOR FIELD CURRENT	
	AS READ	TRUE	AS READ	TRUE
	K = ÷2		K = ÷10	
700	13.0	6.5	17.5	1.75
900	17.0	8.5	17.5	1.75
1100	20.4	10.2	17.5	1.75
1300	24.0	12.0	17.5	1.75
1500	28.0	14.0	17.5	1.75
	K = X5			
1700	3.2	16.0	17.5	1.75
1900	3.5	17.5	17.5	1.75
2100	4.0	20.0	17.5	1.75
2300	4.3	21.5	17.5	1.75
2500	4.7	23.5	17.5	1.75
2700	5.1	25.5	17.5	1.75
3000	5.6	28.0	17.5	1.75

FIG. 426.—Typical log of results of speed vs. terminal voltage, Liberty generator separately excited at normal field current without voltage regulator.

each man watching his instrument. As soon as the tachometer shows the desired value, the tachometer man signals and the instrument men

will note the readings and give them to the log-keeper in the proper order. This procedure should be repeated until the desired maximum speed of 3,000 r.p.m. has been reached. A typical set of results as recorded in the log are shown in Fig. 426.

Curves of Results. After the entire tests have been completed all readings are corrected for meter constants as shown in the typical log sheets. One curve is then drawn for each test.

For the test of field current against terminal voltage field current values are plotted as abscissa and terminal voltage as ordinates as shown in Fig. 427. As seen from the curves the voltage at first increases rapidly

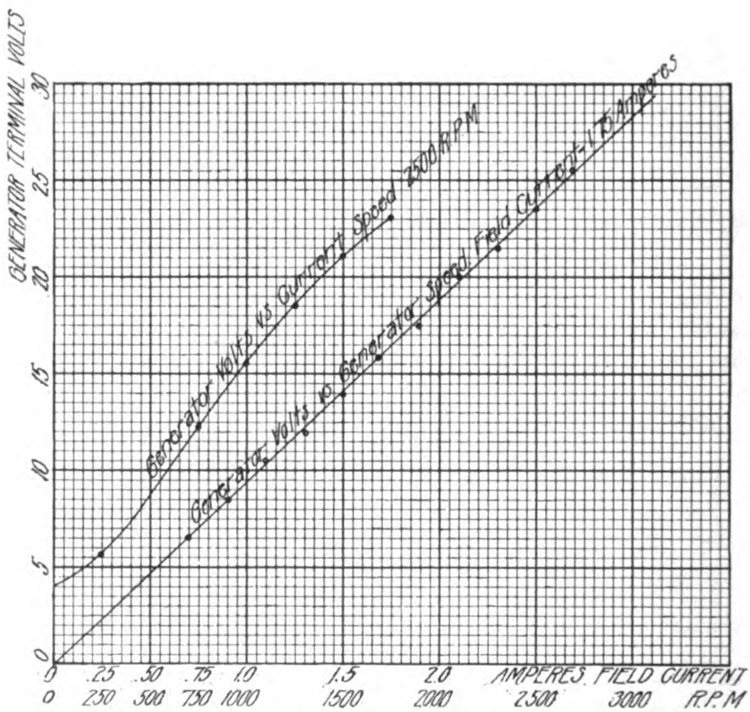

FIG. 427.—Characteristic curves of Liberty generator operating without voltage regulator.

with increased field current up to about 0.75 amp. from which point the curve begins to bend over. Above 0.75 amp. it requires a greater increase in field current to give a certain increase in terminal voltage than was the case below 0.75 amp. This is due to the fact that the field magnets are approaching saturation.

The curve of speed against terminal voltage is plotted with speed as abscissa and terminal voltage as ordinates. It is seen to be a straight line as would be expected from the theoretical considerations which state that the generated voltage is directly proportional to the speed.

The above mentioned curves plotted from the typical results as given in the log-sheets are shown in Fig. 427.

Wound-armature Magnetos, Typical Aircraft Engine Types

251. Disassembly. Disassembly of a typical wound-armature magneto into subassemblies, noting various clearances and adjustments, will be

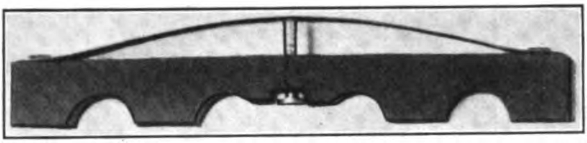

FIG. 428.—Terminal plug clamp assembly.

treated. Study the principle of operation of each sub-assembly. Study the structure and material of each part, referring to the disassembled magneto parts which are mounted. Compare wound-armature magnetos differing in construction details.

Operations in disassembly. Structure and material of each part. The following discussion applies directly to the Berling magneto, type

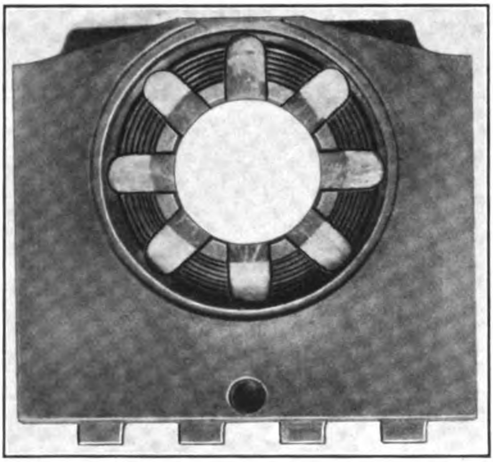

FIG. 429.—Distributor block assembly.

D81 × 3; but the general idea may be applied to any wound-armature magneto.

Terminal-plug Clamp Assembly. Press down on the spring on the terminal-plug clamp assembly and remove it from the bracket. The high-tension lead terminals can now be readily removed.

Distributor-block Assembly. Push down on the distributor-block clamp spring and remove, thus releasing the distributor block cover.

Remove the revolving distributor-finger assembly by pulling straight forward, noting that the high-tension pencil makes up part of this assembly. This pencil distributes the current to the distributor block. A carbon brush in one end of the pencil collects the current from the yoke

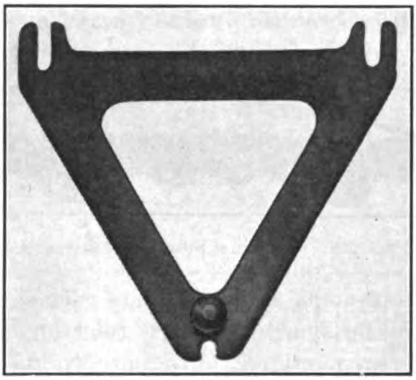

FIG. 430.—Distributor-block clamp-spring assembly.

assembly and conducts it to the distributor block by means of a gap distributor. The distributor finger is so rigidly fixed that there can be no interference between the point and the distributor segment. The segments are of sufficient size to successfully dissipate the heat generated

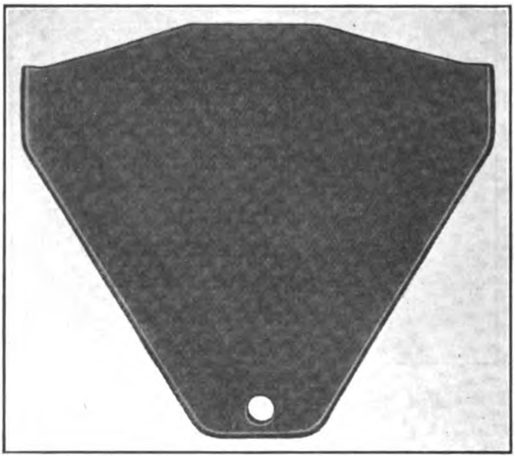

FIG. 431.—Distributor block cover.

by the spark crossing the gap. The point in the distributor finger is made of pure nickel and is of sufficient size to remain cool at all times.

Due to the fact that the distributor block, with its attached cables, is entirely insulated from the magneto winding, a condenser effect takes

place which serves to concentrate the high-tension current and provide slightly better ignition. This does away with the carbon brush, as shown in Fig. 432, and rubbing contact in the distributor system. The latter system requires constant attention to insure that the brush has an even bearing on the distributor rotor track and that the brush works freely in its brass sleeve or retainer.

The gap-type distributor also eliminates fouling of the distributor-rotor track caused by the wearing of the carbon brush. It is important

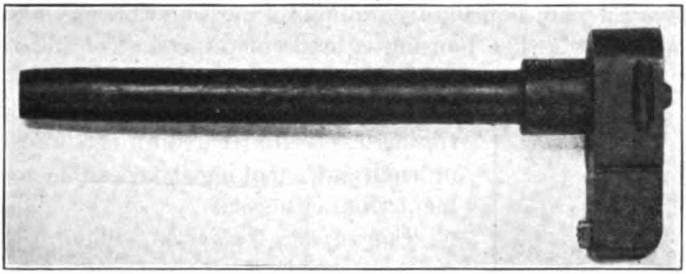

FIG. 432.—Distributor finger assembly.

that the rotor track be kept clean. The segments should be inspected to see that they have not become pitted.

The result of a dirty or fouled block can be illustrated readily by pencil markings in the track. The carbon will readily conduct the current to the wrong segment. This is a common cause of difficult starting, missing, and pre-ignition.

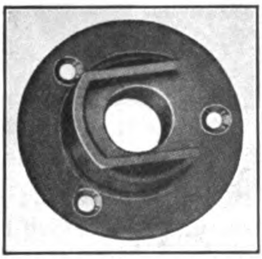

FIG. 433.—Distributor finger locating bushing.

FIG. 434.—Interrupter-housing cover.

Note the method of driving this distributor finger, in that it revolves with the distributor gear. The finger is located in, and driven by the distributor finger locating bushing, which is a hard rubber block recessed to receive the finger, and secured to the distributor gear by three small screws.

The firing order determines the wiring from the distributor block to the plugs. The numbers on the distributor block indicate the order in

which the current is lead to the distributor-block terminals, and not the cylinders to which the terminals should be connected.

Remove the distributor yoke-mounting screw, releasing the distributor block.

Cam Housing. Remove the cam-housing cover by sliding, the cam-housing clamp to one side. The cam-housing cover contains the interrupter-cover contact spring and ground terminal.

Most magnetos use a pressed brass or steel cam-housing cover and use a fiber insulating washer between the housing and cover.

Remove the cam housing by pulling forward or working it back and forth if necessary. The housing is made of pressed steel and the cams are pressed in or embossed at 180 degrees apart, and then hardened and ground. The timing levers are riveted on this housing, one on each side, making it accessible to attachment from either side.

Interrupter Assembly. Slide the interrupter-screw lock clamp to one side. With a 1/4-in. wrench, remove the interrupter hexagonal mounting screw, at the same time holding the armature from turning. Remove the interrupter assembly from armature shaft by pulling forward. Note the keyway in the armature shaft and the key on the interrupter base. This interrupter or current-breaker assembly, accomplishes the breaking of the primary circuit. It consists essentially of a stationary, grounded contact point, and a movable contact point which is mounted on the end of the interrupter lever, both of which are keyed to and rotate with the armature shaft. The movable contact is insulated from the supporting disk, while the stationary contact point has a direct metallic connection with the base, which is grounded to the frame of the magneto by a carbon brush. On the other end of the interrupter lever is fastened a fiber

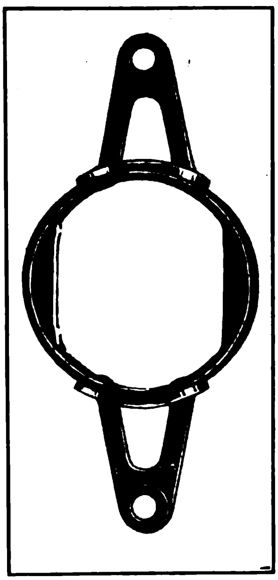

Fig. 435.—Cam housing.

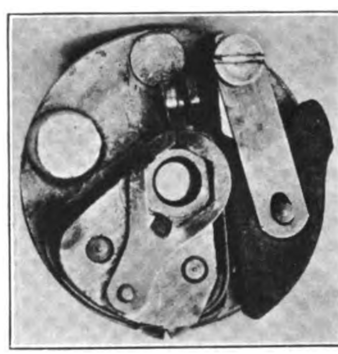

Fig. 436.—Interrupter.

rubbing block which, as the interrupter base revolves, is actuated by the cams in the cam housing. This fiber rubbing block has a tendency to wear down, which results in the points not opening far enough. Therefore as the block wears the point adjustment must be checked. On this machine the movable point is secured to a strap spring and insulated from the base. As the fiber rubbing block leaves the cam, this spring causes the points to close. One end of the primary winding of the armature is connected to the stationary contact block through the interrupter-mounting screw, which screws into a brass insert in the center of the armature to which the primary is directly connected. The screw is insulated from the base by a fiber washer.

Yoke Assembly. Remove three small screws holding the yoke assembly and remove it. This assembly is made up of hard rubber with a bronze conductor molded in it.

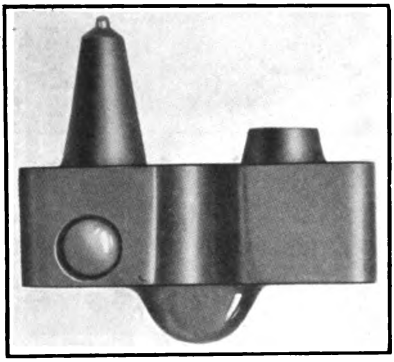

FIG. 437.—Yoke assembly.

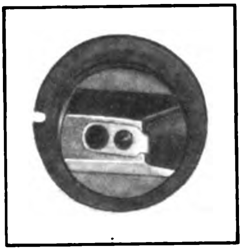

FIG. 438.—Brush-holder assembly.

There are three terminals; one conducts the current from the high-tension collector-ring brush, through a long bronze screw with a hard-rubber housing or insulator, inserted through the bottom face of the yoke. Current is then lead to a terminal in the center of the yoke. There is a housing around this terminal which receives one end of the high-tension pencil, whose collector brush makes contact with this terminal and conducts the current to the distributor.

The third terminal can be utilized to collect current from the collector-ring brush in the case where a double-distributor block for double ignition is used.

High-tension Brush Holder. Slide the brush-holder clamp aside and remove the brush-holder cover and assembly. This includes the safety spark-gap assembly. This gap consists of a small chamber assembly attached on the side of the magneto at the collector-ring end, taking the secondary current directly from the collector ring. The inside of this chamber has an insulated lining of porcelain with a terminal which makes

contact with the high-tension brush, inserted in the base. The metal cap or cover carries the grounded terminal inserted.

This cap has six small holes drilled in its face for ventilation, and if the gap functions, the spark can readily be seen. It has a wire gauze lining to keep out all foreign substances. The gap is set at ⅜ in. and functions when a faulty condition exists in the secondary circuit, thus protecting the insulation on the secondary winding.

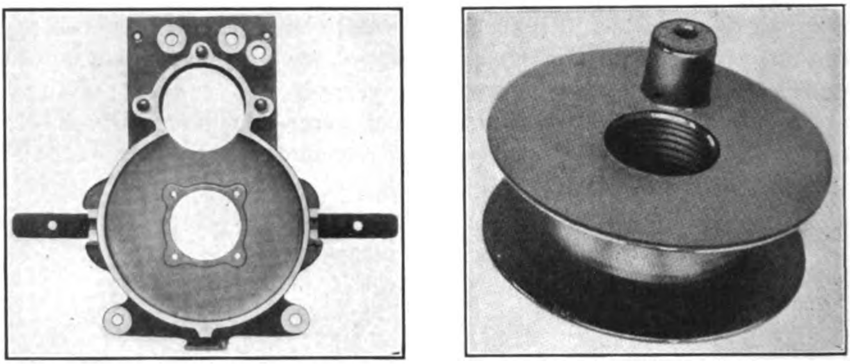

Fig. 439.—Collector spool.

The collector brush is inserted in a brass retainer and held against the collector ring by a spiral spring. A brass segment has a direct bearing on the brass retainer thus forming a path for the current to be led through the yoke assembly. The collector brush must have a clean even bearing on the collector ring, must work free in its brass holder, and must have proper spring tension behind it. The brush-holder assembly is made of hard rubber.

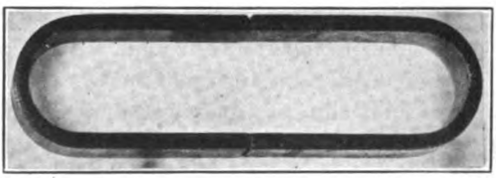

Fig. 440.—Magnet.

Magnet Assembly. Remove the brass magnet strap held by two screws and two small plates at the sides of the magneto base. This leaves the permanent magnets free to be lifted from the machine. In removing the magnets place a keeper between the poles to retain the residual magnetism or take the magnets and place end to end so that the north pole of one is in contact with the south pole of the other. The magnets are made of chromium or tungsten steel.

Armature and Bearing Assembly. The bearing assembly should next

be removed. Before beginning this removal, it is a good plan to check up clearances and backlash and condition of distributor and pinion gears. This will aid in checking on reassembly. Remove four screws and take off the brass driving end plate and bearing assembly.

The armature rides in annular ball bearings with oil guards, so that any lubricant supplied to them will not be easily lost, or reach the insulating parts.

Remove two screws and the cam-housing clamp stud and remove the interrupter-end plate and bearing assembly. The armature can now be removed from the drive end of the magneto.

Examine the armature assembly, noting that the end pieces are of soft cast iron, while the core is made up of soft-iron laminations. The laminations and end pieces are held together by dowel-pins. This core of soft iron serves as a path for the magnetic flux between the pole-pieces, and carries the primary and secondary windings.

FIG. 441.—Armature assembly.

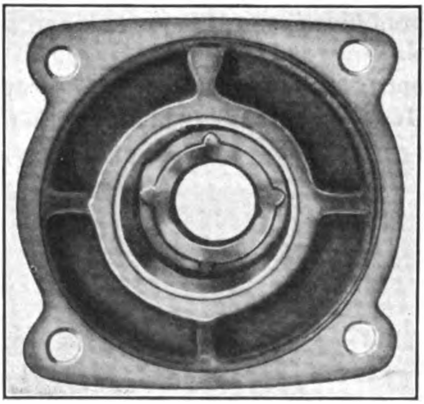

FIG. 442.—Driving end-bearing assembly.

The core is first insulated with mica or similar material, to insulate the primary winding from the core. One end of the primary is grounded to the armature core, while the other end is connected to a terminal at the interrupter end of the armature, which in turn is connected to the interrupter point through the interrupter mounting screw.

Over the primary winding an insulating fabric is wrapped, over which the secondary is wound. The secondary winding consists of several thousand turns of very fine wire. One end of the secondary is grounded to the grounded end of the primary. The other end is carefully insulated and makes connection to the collector ring mounted on the armature shaft. This collector ring is a bronze ring molded in a hard-rubber spool.

The current is collected and then led to the high-tension pencil by a heavily insulated, stationary carbon brush, which bears upon the collector ring. The hard-rubber spool has wide flanges for the purpose of preventing the high-tension current from escaping.

Over the secondary winding insulating cloth is wrapped and is held in place by windings of silk thread shellacked to prevent the wire and insulating

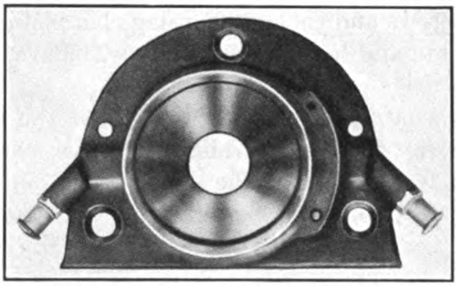

FIG. 443.—Interrupter-end bearing assembly.

material from flying out at high speed and coming into contact with the pole-pieces.

The condenser is located in the interrupter end of the armature assembly It is connected in parallel with the interrupter points. One end of the condenser is connected to the non-grounded end of the primary

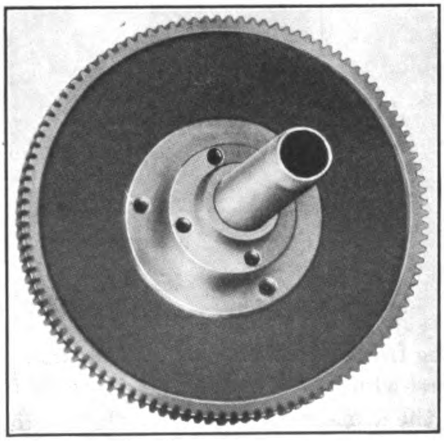

FIG. 444.—Distributor gear.

and the other is directly grounded. This condenser is built up of alternate sheets of tin foil and mica. Alternate sheets of tin foil are connected to one terminal of the condenser, while the remaining sheets of tin foil are connected to the other terminal. The capacity of this condenser is .020 microfarad.

Distributor Gear Assembly. After removing three screws, take off the distributor-finger locating bushing. This bushing is made of hard rubber and recessed to receive the distributor finger of the high-tension pencil and to drive it.

FIG. 445.—Distributor finger-locating bushing.

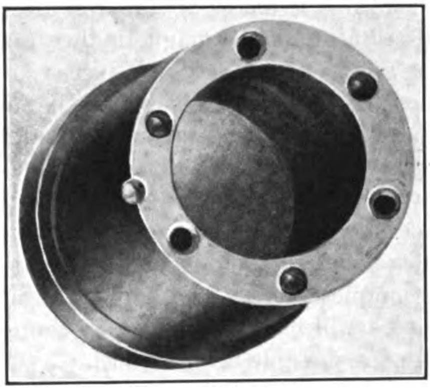

FIG. 446.—Adjustable bearing bushing.

Examine the insulation for cracks. Remove the three distributor-bearing screws, and slide out the distributor gear and bushing. This bushing is made of brass, and is of the eccentric type, making it possible

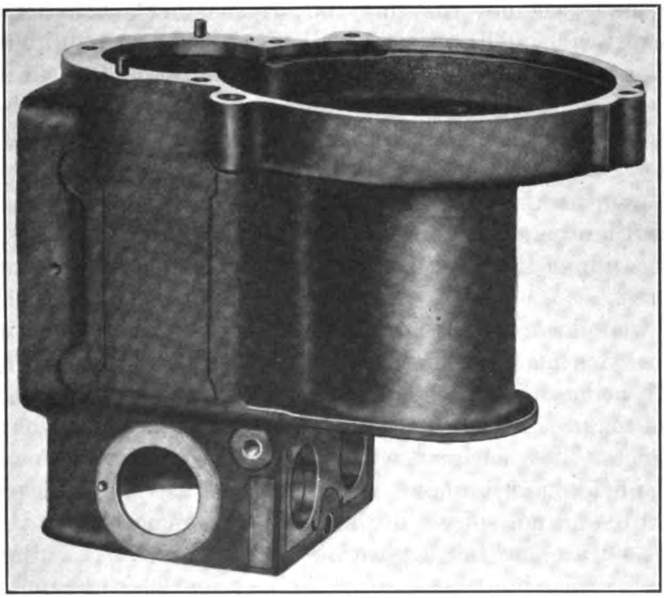

FIG. 447.—Frame assembly.

to get the desired clearance between the steel distributor pinion and the bronze distributor gear.

This leaves the bronze frame with a cover over the armature tunnel to keep out foreign substances. The magneto frame always must be made of some non-magnetic material so that the lines of force will not travel through the frame instead of through the armature core.

Two pole-pieces of soft iron are cast in this frame to provide for the distribution of the magnetic flux. After the magneto has been in service for a long time, these pole-pieces sometimes have a tendency to become loose. This trouble is due to the fact that in some cases there is an air space between the pole-pieces and the bronze frame, and it can not be seen without cutting through the casting. This trouble can be remedied by drilling holes through the frame at each corner of each pole-piece, making eight holes in all, and driving in dowel pins. Care should be taken to see that the pole-pieces are in the correct position when this operation is complete. Any variation in the air gap between the armature and pole-pieces will cause a change in the efficiency of the magneto as well as causing possible interference.

While all wound-armature magnetos are similar in general construction, the various makes differ from each other in some details. On the Berling, the common practice of rotating breaker mechanism with stationary cams and cam housing is carried out. One breaker point is stationary, while the other is movable, being actuated by the embossed cams. If these cams wear down and the points do not function properly, there is no provision made whereby they may be adjusted. The cam housing with the embossed cams and possibly the fiber bumper may require renewing.

On some other makes of magnetos the cams are made of fiber or steel and are secured to the housing by two small screws. When these cams wear down it is possible to remove them and insert shims, thereby bringing them again into the proper position.

In some types the primary winding is connected to the fixed breaker point while in others it is connected to the movable breakers.

The location of the safety spark gap also varies in the different types of magnetos.

Some wound-armature magnetos use pivoting or rocking field magnets. The Mea magneto has bell-shaped magnets instead of horseshoe magnets, it being claimed that the bell-shaped magnets will hold a greater amount of magnetism and will retain it longer than the ordinary horseshoe magnets. The entire magneto is carried in a trunion mounting, so that the field magnets move with the advance lever. This plan keeps the armature and pole-pieces in the same relative position at the instant that the points open, in all positions of the spark advance lever. An advantage of this type is easy starting, as a spark of the same intensity is produced at both advance and retard spark position.

252. Assembly. This includes the assembly of all subassemblies, checking all clearances and making adjustments as the work proceeds.

Press the adjustable bearing bushing into the frame assembly. Care should be taken to match the slot in the bearing bushing with the pin in the adjustable bearing clamp-ring. Replace the three distributor-bearing screws, the distributor gear which is secured with four screws, and to this, attach the distributor locating bushing and secure it with three screws. Be sure these assemblies are all in proper line before inserting their retaining screws, as it is a very easy matter to strip the threads on these fine screws.

Place the armature assembly in the frame assembly from the driven end and mesh the distributor gear with the distributor pinion, noting punch marks on the teeth of the gears.

Grease the end-bearing assemblies, secure the driving end assembly with four screws, secure the interrupter-end assembly with two screws and the cam-housing clamp stud. Now check the clearance between the distributor gear and the pinion; it should be .004 in. or .005 in. This clearance can be adjusted by means of the distributor-gear eccentric bushing. Test the armature bearings for end play, the maximum allowable end play is .002 in. If the end play exceeds this amount a shim washer should be placed between the inner ball race and the distributor pinion. After final adjustment of the bearing, stake the bearing-assembly screws with a center punch.

Shaft Coupling. Replace the coupling key and the shaft coupling and secure with a retainer nut.

Magnet Assembly. Recharge and replace the two magnets, being sure that like poles are on the same side. Determine the polarity by the attraction and repulsion method. Rotate the armature by hand and just as the armature is about to leave the field pieces a resistance will be felt caused by the breaking of the lines of force. If little resistance is felt it is an indication that the magnets are weak. An ordinary magnet should lift about 15 lb. If the magnets are of proper strength, place a strap over the magnets and insert the screws and steel plate to secure the magnets.

High-tension Brush Holder and Safety Spark-gap Assembly. Place the collector-brush spring and the collector brush in the brush assembly and install this assembly in the frame assembly. Replace the brush-holder cover and secure with the brush-holder spring clamp.

High-tension Yoke Assembly. Install the yoke assembly and secure it with three screws. Be sure the yoke finger makes a good contact with the brush-holder assembly.

Interrupter Mechanism. Install the ground brush and spring in the interrupter base. Place the interrupter assembly in position and secure with the interrupter-mounting screw. Great care must be taken to see that the key on the interrupter base fits exactly into the keyway on the

armature shaft. Replace the cam housing making sure it is replaced in exactly the same position from which it was taken, and see that it does not bind or stick. Adjust the interrupter points by placing the fiber breaker arm in the center of one of the embossed cams. The opening between the platinum contacts should be not less than .016 in. nor more than .020 in. The contacts must be smooth and clean and make contact with each other over their entire surfaces. After final adjustment, secure the platinum screw with the interrupter locking screw. Replace the cam housing cover and secure with the cam housing clamp spring.

Distributor-block Assembly. Replace the distributor block and the distributor-yoke mounting screw. See that the rotor track is absolutely clean and that the segments are free of pits. The high-tension pencil makes up part of this assembly. Install the high-tension pencil. This will cause the distributor finger to set in the recess in the distributor finger-locating bushing. Check the rotor brush position on the segment against breaker point opening position. The distributor brush should be fully on segment when the points break, although a tolerance of $\frac{3}{32}$ in. is allowed. The edge distance on this magneto is the distance between the point of magnetic break and the point of opening of the interrupter contacts in the full advance position, this distance being $\frac{5}{32}$ in. to $\frac{3}{16}$ in.- from the trailing pole, with the spark advanced. Replace the distributor block cover and secure with the clamp spring. Replace the terminal-plug clamp bracket and secure with two screws. Replace the terminal-plug clamp assembly.

The changes necessary to make a magneto function properly in the reverse direction follow:

Reset the distributor in relation to the armature break. That is, instead of rotating the magneto clockwise rotate it anti-clockwise and set the armature from $\frac{5}{32}$ in. to $\frac{3}{16}$ in. from the trailing pole in an anti-clockwise direction. Now set the distributor brush fully on No. 1 segment. It will now be necessary to get a new, or left-hand, breaker mechanism. Install the same and check the interrupter points, or see that they raise, breaking the armature current, just as the armature is the proper distance from the edge of the pole-piece.

The firing order must first be determined before wiring up to the engine.

253. Operation. The magneto is first driven at low speed, 100–150 r.p.m., with all high-tension leads connected to adjustable gaps. The maximum gap that the secondary voltage will jump at this speed should be noted. The magneto should then be driven at high speed, about 3,000 r.p.m. It will be noted that the secondary voltage will jump a larger gap at high than at low speed. Instead of using a variable gap in air, a preferable way is to test the spark under compression. This can be done by constructing an airtight chamber inside of which are mounted spark

gaps which can be adjusted from the outside of the chamber. A piece of plate glass in one wall of the chamber will permit of the spark being seen. The pressure can be raised to any desired amount and the maximum spark at that pressure noted.

The position of the timing lever should be changed, and the effect on the length of spark noted.

Non-wound Armature Magnetos (Dixie), Typical Aircraft-Engine Types

254. Disassembly. Disassemble a Dixie magneto and study the principles of operation of each sub-assembly. Study the structure and material of each part, referring to disassembled magneto parts which are mounted.

Although the following discussion applies directly to the Dixie 800, the general idea can be applied to any non-wound armature magneto.

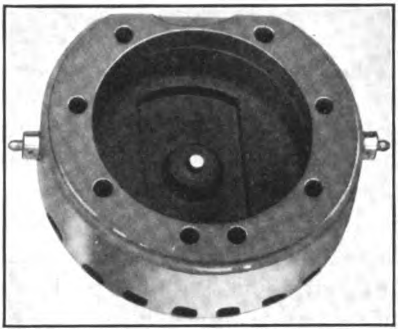

FIG. 448.—Dixie 800 distributor block.

Distributor Assembly Remove the distributor block by releasing the distributor-block clamp springs. This block is made of Americanite. There are eight brass segments 45 degrees apart embedded in the block. High-tension cables running through eight holes in the block connect to the segments. In the center of the inside of the block, a brass brush holder is embedded. One end of the holder forms a stud, which protrudes from the outside center of the block to accomodate an Americanite thumbnut. This stud forms the connection to the hand-starting magneto. Two bronze lugs are attached to the sides of the block which receive the distributor clamp springs. The rotor track should be inspected to see that it is clean.

Breaker Cover Assembly. Unscrew the Americanite thumbnut on the primary grounding stud and remove the bushing. Slide the breaker cover latch to one side and remove the breaker cover. This cover is made of sheet aluminum.

Condenser. With the Dixie magneto wrench remove the two con-

denser clamp nuts and slip off the condenser. This condenser is built up of 104 layers of mica .001 in. thick, alternated with sheets of tinfoil. One piece of mica .010 in. thick is placed on the front and back of the condenser. One-half of the layers of tinfoil are soldered together at one

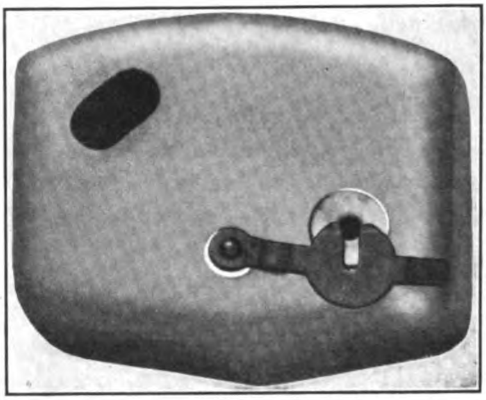

Fig. 449.—Breaker cover assembly.

edge of the condenser, and the other half, are soldered together at the other edge. The capacity of this condenser is from .150 to .220 microfarad. It is placed across the breaker mechanism.

Radio Terminal. Remove the two screws and remove the radio terminal with the collector brush and spring, piercing screw and gasket. This terminal is made of Americanite, with a brass brush which collects its current from one end of the safety spark terminal.

Magneto Cover and Clamp Assembly. Remove four screws from the two magnet-cover

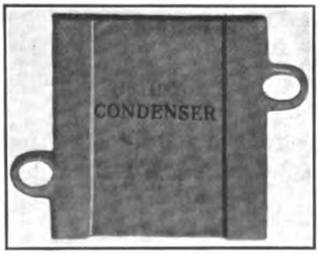

Fig. 450.—Condenser.

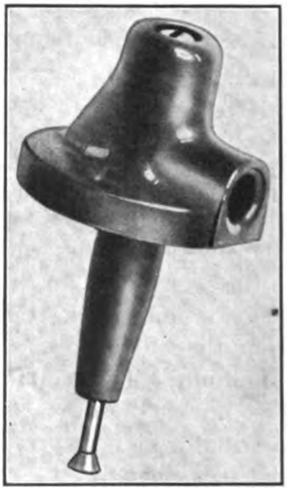

Fig. 451.—Radio terminal.

clamps and lift off the aluminum cover. This cover fits down onto felt gaskets and keeps out all foreign matter and dampness. With a ¼-in. open-end wrench, remove the two nuts and washers which hold

the magnet clamp, and, with a screw driver remove the end of the magnet clamp from the magnets.

This clamp which is made of steel, serves to hold the magnets firmly in the frame. The magnets can now be removed from the machine. Before so doing, however, place a keeper between the poles of each magnet. These magnets are made of tungsten steel. There are two supports at the base of the magnets, which may be lifted out.

They are channel sectioned and made of

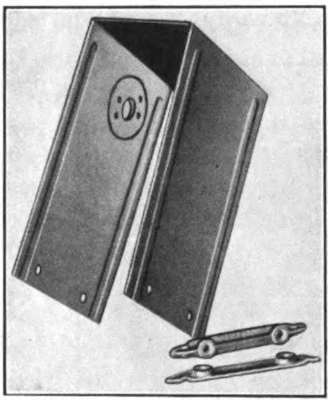

FIG. 452.—Magnet cover and clamp assembly.

FIG. 453.—Magnet clamp.

steel. Note that the magnets are attached to the machine so that both north poles are situated at one end of the rotating member, and both south poles at the other end of the rotating member. On a wound-armature type, the magnets straddle the rotating member. The method

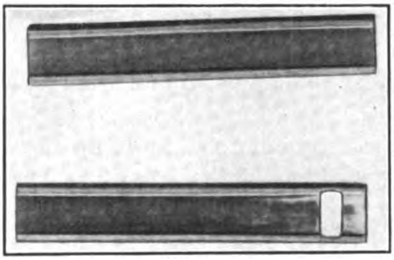

FIG. 454.—Magnet supports.

utilized on the Dixie, therefore, necessitates a semicircular cut in adjacent halves of the magnets to allow the shaft of the rotating member to pass through.

Coil Assembly. Remove the ground-connection screw which secures the connection between the primary and the frame. Then remove the

screw and the washer on the breaker assembly, which holds the primary lead wire. There is an enlarged hole in the aluminum base plate, and the wire can be removed by pulling it through this hole. Loosen the four lock-nuts on the four winding clamp screws, then loosen the four screws and slide the winding clamps aside leaving the coil free to be removed. The whole unit lifts out of the laminated field-pole structure. This assembly consists of the core, which has forty-nine .014-in. laminations of soft iron with two .031-in. end laminations, using three Norway-iron rivets which hold the laminations in a unit. A varnished silk insulation is wound around this core, and over this the primary winding, consisting of about 200 turns of No. 21 wire is wound and insulated with

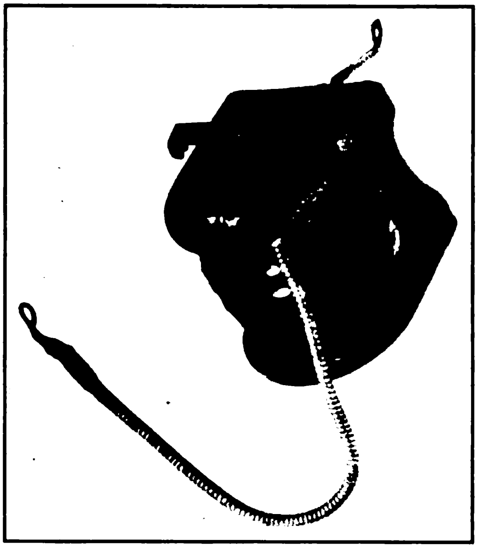

FIG. 455.—Coil assembly.

varnished silk. The secondary is wound with about 9,000 turns of No. 36 enameled wire.

The layers of the secondary are built up in a pyramid, each layer being a little narrower than the lower layer. This is to afford a better means of preventing the winding from breaking down along the end plate to the core. A piece of rice paper .001 in. thick is placed between each layer extending all the way across the coil from one end plate to the other. The coil ends are made of fiber and are pressed onto the core. A hole is drilled in the end piece to bring through the primary-ground end. The outside of the coil is covered with varnished silk and the whole is impregnated with insulating varnish. One end of the secondary is connected to a brass insert which makes connection with the distributor-collector brush. This insert is located on the side of the coil assembly.

The safety-spark gap constitutes part of the coil assembly. One terminal is made of Americanite with a brass insert and the other terminal is a brass strip connected to the primary-ground lead. The non-grounded terminal of the safety gap also forms a connection to the radio terminal.

Distributor-rotor assembly. Remove the high-tension distributor rotor by removing the two cotton pins, nuts, and washers. The rotor will then slip from the studs. This assembly is made of Americanite. Remove the snap ring on the hard-rubber gap protector and remove the protector. This gap protector fits into a recess cut into the inner face of the distributor-bearing holder. Inspect these parts for cracks. Inspect the carbon distributor brush and see that it works free in its phosphor-bronze retainer. Inspect the carbon collector brush, retainer and spring. Note the tinned-brass trailing brush in this assembly, which is used for starting purposes. This brush is entirely insulated from the high-tension circuit of the magneto and is connected only to the hand starting magneto. It is set 40 degrees behind the main distributor brush, thereby insuring that the spark from the hand-starting magneto will occur when the piston is past top center. The trailing brush is a non-contact or gap type, there being a small clearance between its point and the segment of the distributor.

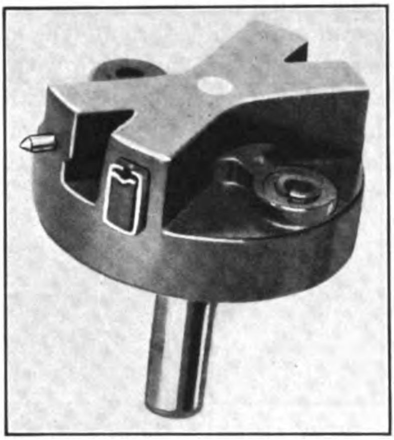

Fig. 456.—Distributor-rotor assembly.

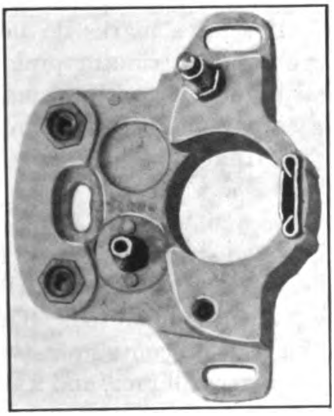

Fig. 457.—Breaker-base assembly.

Breaker-base assembly. Remove the breaker-bar spring screw and breaker-bar reinforcing spring. This spring closes the points as soon as possible, after they have been opened by the cam action. Slip the breaker-retainer spring aside and remove the steel breaker bar complete with the spring and platinum point. This bar has a tobin-bronze bushing and an Egyptian-fiber bumper which must be inspected for wear. Remove the three breaker-base plate fastening stud nuts and brass lock cups; and remove the aluminum breaker-base plate from the studs. These studs pass through slots in the breaker-base plate and permit the adjustment of the rotor-wing gap. This assembly

contains a felt cam oiler set in a soft brass retainer in the peak of the assembly to provide lubrication for the cam.

Upper and lower tie rods and back bearing-plate assembly. With a ¼-in. wrench remove the two locknuts and the two hold-down nuts and washers and pull out the two lower brass tie-rods. Remove the upper tie-rod nuts and slip off the die-cast, aluminum back-end plate. A recess is cast in this plate with a hole in the top of the recess for the magnet-clamp bolt to come through. On the bottom of the recess is an oil cup which leads to the oil hole in the top of the bearing holder. Care should be taken to remove the plate parallel to the shaft. Now remove the upper tie-rods with a ¼-in. wrench.

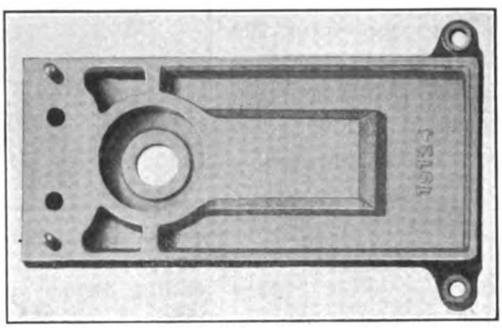

FIG. 458.—Drive-end bearing plate assembly.

Front bearing plate assembly. Check the service marks on the distributor pinion and the distributor gear. If service marks do not exist or do not correspond, mark one tooth on the distributor pinion and the two corresponding teeth on the distributor gear with a small punch. Check up for blacklash and wear of the gears. With a hammer and a fiber block, remove the front bearing plate from the cradle. Care must be taken to remove the plate parallel to the shaft.

The front bearing plate is a die casting of aluminum. It forms a housing for the distributor-gear pinion and the distributor gear. It also provides a means of holding the distributor-gear bearing and the bearing-base plate on which the breaker mechanism is mounted. The distributor bearing is built up of steel bearing holder containing two outer ball races held apart by a brass spacer, one inner ball race, and a set of balls. This bearing assembly is pressed into the front plate and secured by four screws.

Distributor drive assembly. Remove the four screws from the distributor-bearing cage and remove the cage with the gap-protector snap ring and gap-protector sleeve. With a special wrench remove the distributor-bearing nut and washer. With a hammer and a fiber block remove the distributor gear. This gear rides in Norma ball bearings.

It is a bronze casting with 80 teeth and runs at half the speed of its steel driving pinion. The distributor spool is made of Americanite, and carries two distributor brush assemblies, the carbon brush for running, and the trailing pin for starting purposes.

Rotating-pole structure. Remove the four screws from the breaker end of the bearing holder and the four screws from the drive end of the bearing holder. With a hammer and fiber block drive the rotating-pole structure from the drive end of the bearing holder. This assembly contains the four-lobe cam, two ball-bearing assemblies, and the distributor gear driving pinion. The rotor shaft is made of tobin bronze and is non-magnetic, thereby preventing the flux from passing through the shaft from one set of wings to the other. Each pair of these wings makes contact with the steel bearing holders against which the soles of the magnets fit. This rotor with a four-lobe cam, produces four sparks per revolution, thus cutting down the speed to half that of a wound-armature type magneto. The cam is made of .2 per cent. carbon steel, case-hardened and is retained on the shaft by a key and a cam-retainer screw.

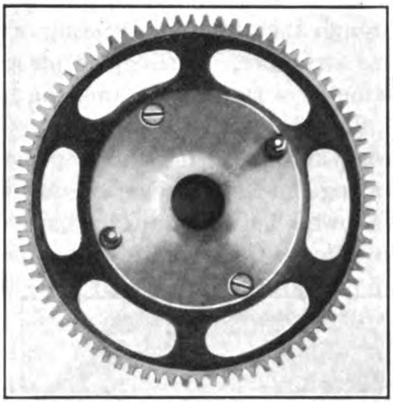

FIG. 460.—Distributor-drive assembly.

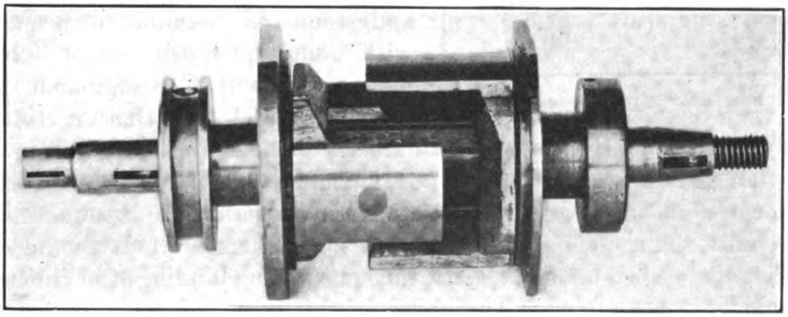

FIG. 461.—Rotating-pole structure.

The distributor-gear driving pinion is keyed on the breaker end of the shaft and is made of steel. It has 40 teeth, one half the number of teeth of the bronze distributor gear. The bearing assemblies, which carry the rotating member, are pressed on the shaft with their bearing holders.

Cradle assembly. The cradle assembly is sometimes called the magneto base. It carries the laminated field-pole structures. The cradle is

die-cast aluminum. It is light in weight and non-magnetic. The field-pole assemblies are each made up of 98 laminations of .014 in. stock with two end laminations of .031 in. stock, held together by three rivets. The rivets in the protruding ends of the poles extend on either side forming lugs on which the retainer clamps hook. The lower rivets protrude through the aluminum casting of the cradle, securing the pole pieces to that structure. These pole pieces extend down about one-third of the diameter of the circular opening for the rotor wings.

255. Assembly. *Rotating structures.* After the cradle assembly has been thoroughly inspected, place the rotating-pole structure with the bearing holder and bearing assembly into the cradle. Sufficient space is allowed, between the face plate of the holder and the ball race, to allow the poles of the magneto to be inserted. Observe that the oil hole in the outer ball race is at the top. Replace the four flat-head screws which secure the bearing holder to the cradle. It will be noticed that the breaker end bearing holder flange is much thicker than the other. The reason for this is that this end acts as a thrust bearing, as there is always a force acting upon it. It is made heavier to compensate for this additional strain. Press the drive-end bearing holder assembly on the drive-end of the shaft, check for the correct oil hole piston and secure the assembly to the cradle with four flat-head screws. Now check the shaft for alignment and clearance, and see that it rotates freely. If the shaft does not rotate freely, check each bearing holder and see that it is pressed in proper position upon the shaft. Trouble may be located in the spacer washer which is placed on the breaker end of the shaft. This washer is about .004 in. in thickness. It should spin freely when placed upon the shaft, thus preventing binding after the bearing holder is assembled. The object of this bearing holder spacer is to prevent the breaker-end bearing holder from being pressed too far upon the shaft. Since the breaker-end bearing holder is assembled to the shaft first, there would be no means of regulating the distance that the bearing holder is to be pressed upon the shaft if this spacer were not present. If this holder is pressed on too far or not far enough, the clearance between the rotor wing and the respective bearing holders will be incorrect and binding will result.

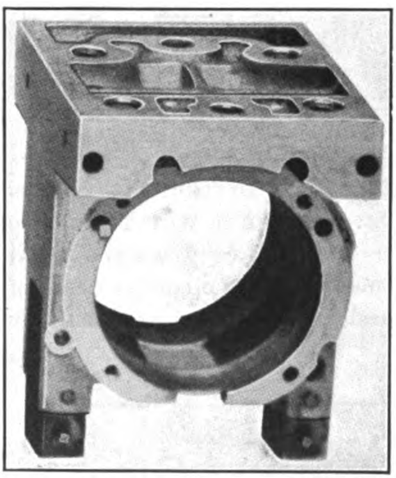

Fig. 462.—Cradle assembly.

Cam and distributor pinion. The distributor pinion is a steel gear

having 40 teeth. There are eight holes drilled in the web of the pinion to reduce its weight. A felt oil-retaining washer is placed in the groove of the pinion and the pinion is then pressed into place on the rotor pole shaft.

The interrupter is actuated by a four-lobe cam made of hardened steel and ground. The cam is made with a sleeve and collar through which the shaft fits. The cam is keyed to the shaft and further secured by the cam-retainer screw which screws into the breaker end of the shaft. The collar of the cam should fit against the boss of the pinion.

Distributor-drive assembly. Place one distributor bearing in the front bearing plate and press it in until the bearing comes up tight against the shoulder on the bearing cage. Press the distributor-gear shaft into the bearing which is assembled in the bearing cage. Place a spacer washer, which regulates the end play, and the second ball-bearing set on the distributor-gear shaft. Press the bearing on the distributor-gear shaft and into the distributor-bearing cage. Place the distributor-bearing nut washers and nut on the shaft and secure the nut with a hammer and punch.

Front bearing-plate assembly. Place the front bearing-plate assembly on the cradle assembly and tap it into place with a hammer and fiber block, care being taken that the bearing plate goes on evenly over the bearing and the two dowel pins in the cradle assembly, and that the punch marks on the distributor gear correspond with the marks on the distributor pinion. At the two upper corners of this plate are two bosses in which the upper tie rods fit. Replace these two tie rods. Between these two bosses and at the extreme top of the plate is the oil reservoir with a spring cover. Two oil leads are drilled down through the plate, one oiling the distributor bearing, the other supplying oil to the front main bearing. There is a groove cut in the shoulder along both sides and the top of the inside face of the plate in which is inserted a strip of felt. The magneto cover when in place, fits tightly down on this shoulder and felt pad. The pad prevents rattling and keeps out dust and moisture.

Back bearing-plate assembly. This plate is similar to the front plate and is of cast aluminum. There are two corresponding bosses at each upper corner, drilled to allow the threads of the upper tie rods to slip through. A shoulder extends around the inside edge of this plate as on the front plate and is grooved to receive a felt pad. Before assembling these plates, the oil leads should be examined and cleaned out if necessary. Replace the back plate, taking care that it fits evenly. Slip the lower tie rods through and secure them with washers and nuts.

Breaker-base assembly. Replace the aluminum breaker-base plate on the breaker studs. Then replace the aluminum breaker base. T l are three slots through which the three studs fit. This allows for the

adjusting of the breaker opening in respect to the rotor-wing gap. Replace the lock cups and the three nuts on the breaker studs and tighten them lightly with a special slotted-bit screw-driver. A brass clip is inserted in a slot cut in the top of this assembly. This pad holds a felt oil pad which reduces wear on the fiber bumper. On either side of this plate two holes are drilled and tapped. One is to receive the stud to which one of the condenser terminals is attached, forming the grounded side of the condenser. This stud also projects through the breaker cover forming a means of holding the cover in place. A flat-head screw fits into the other threaded hole and holds the breaker-bar finger spring in place. Replace the breaker-bar assembly complete on the breaker-bar stud screw. The breaker-bar finger spring is made of spring steel and is used to hold the breaker bar in place on the shaft. Move the breaker-bar finger spring into position and replace the retaining screw.

The stud for the breaker-bar bearing is made of steel with a flange on one end. This flange sets in a counter-bored hole in the breaker base and is held in place by two rivets. A contact-screw bracket made of bronze is secured to the breaker base by two flat-head screws. At one end of this bracket is a screw to which the primary-lead terminal is attached. On the other end of the bracket is screwed the bronze primary-ground stud and the platinum screw. The other condenser terminal slips on this stud forming the primary side of the condenser. The stud projects through a hole cut in the breaker cover, where the ground-stud bushing is slipped onto the stud, and is held in place by the ground-stud thumb nut. This forms a terminal for a lead from the primary circuit to the grounding switch, which, when closed, grounds the primary circuit.

Since one end of the primary coil is grounded to the frame, the other end must be insulated, making it possible to break the circuit with the breaker mechanism. As the breaker bar has been grounded to the frame, it is necessary to insulate the breaker-bar bracket from the frame. This is accomplished by placing a strip of insulating material between the bracket and the breaker base. The two screws that hold the bracket to the breaker base are also insulated by inserting a bushing of insulating material in the hole in the bracket, for each of the two flat-head screws, with a fiber washer placed beneath the head of the screws, thus completely insulating this side of the breaker mechanism. The platinum points are welded to soft-steel screws. When assembling, be sure the points are clean and have an equal bearing on each other. See that the wick is in the breaker stud and that it is properly lubricated. See that all insulators are inserted and that no cracks or flaws exist. Care should be taken in tightening all bronze studs as they shear off very easily. See that the lock-nut is assembled with the adjustable platinum screw. The breaker mechanism has been specially designed to meet the require-

ments of high speed operation. The points are made of platinum and iridium.

Install the key in the driveshaft and place the coupling on the shaft. Secure the assembly with the drive-coupling lock-nut.

Adjustments. Adjust the breaker-gap opening with a thickness gage to .02 in. when the highest point of the cam is in contact with the fiber bumper on the breaker bar. After setting the gap at the proper distance by means of the breaker point screw, tighten the lock-nut on the screw. Check the maximum contact opening caused by the action of the other lobes in the cam. The variation in contact openings should not exceed .002 in. Oil the cam-oiler pad with about three drops of light oil, noting that the felt oiler rubs lightly against the cam. Set the rotor-edge distance by the use of a thickness gage and a buzzer set. Connect one lead to the post that is fastened to the contact-screw bracket and connect the other lead to the post extending from the breaker base. Turn the rotor in the direction indicated by the arrow on the drive-end plate, until a thickness gage of .05 in. to .075 in. can be inserted between the departing edge of rotor wing and field pole. Place the gage in the gap and hold the rotor wing firmly against the gage. Loosen the three slotted nuts that hold the breaker base, and turn the breaker base to the right or left until the buzzer indicates that the points just open. When this has been done, secure the three nuts and check the adjustments. If the adjustments are satisfactory, stake the cupper washers in the slotted nuts to prevent loosening. Replace the pole cover over the armature tunnel.

Distributor-rotor assembly and gap protector. The gap protector is next assembled to the gap-protector sleeve. This protector is a hollow shaft, face molded, of Americanite. The shaft slips into the sleeve and is held in place by a snap ring. A number of concentric rings are molded into the outside face of the protector thereby offering a creeping surface for any stray portion of the secondary current which might tend to jump from the secondary terminal of the coil to the magnets. Replace the collector brush spring in the distributor rotor and place the rotor on the distributor gear. Place the two washers and two nuts on the rotor hold-down studs. Tighten and secure with cotter pins.

Coil assembly. Install the coil unit, first making sure that the collector brush is correctly located. Place the winding clamps on their respective hooks, and tighten the four set screws and secure with the lock-nuts. Pull the primary lead through the enlarged hole in the base plate, and fasten the terminal to the breaker assembly with the screw and washer. Connect the grounding strap, from the terminal on the coil, to the ground. Stake the screws with solder to insure a good contact at all times.

Magnets. The magnets rest on two channeled magnet supports which rest on the extending portions of the base of the cradle. They are placed with the edges up. A slot is cut in the forward support to allow room for the primary lead.

Remagnetize and install the magnets. Keepers should be kept in place until the magnets have been installed. The north poles of the magnets are located at the drive end with but one hole between them. The breaker ends have two holes cut between them. One is to receive the rotor-distributor pencil and gap protector. The other hole is for the rotor shaft and the bearing-holder assembly. When in place, the magnets rest on the magnet supports. Locate the magnets properly and then place the steel magnet strap over the top of the magnets and secure the strap to the end plate with the bolt on the end of the strap. Tighten the nut which holds the magnets in place and prevents vibration and shifting.

Place the sheet-aluminum magnet cover over the magnet assembly. Along the edges of both sides a groove is pressed, in which is glued a felt gasket which aids in keeping out dust and moisture. The groove also aids in stiffening the cover. Secure the cover to the cradle base by two cover clamps, each held on with two screws.

Radio terminal. Install the radio-terminal brush and spring, piercing screw and felt gasket. Install the assembly on the magnet cover with two screws. This terminal was used on early models but is now obsolete. In later models an aluminum cap is placed over this hole.

Condenser. Place the condenser on the studs and secure it with the two condenser-clamp nuts. These nuts hold the condenser firmly in place across the breaker mechanism. Be sure the studs are clean and firmly set.

Breaker assembly cover. Replace the aluminum breaker cover and secure it with the catch. Install the ground-stud bushing and the primary stud thumbnut. One of these studs is the condenser stud, and the other is the primary grounding stud.

Distributor block. Install the distributor block and secure it with two catch springs. Be careful to replace the distributor block squarely to prevent the point of the trailing pin damaging the highly finished surface of the inside of the distributor block. There should be from .015 in. to .04 in. clearance between the end of this point and the rotor track. The distributor carbon brush should be free in its socket and have just enough spring tension to insure good contact with the distributor segments. The rotor track must be clean and smooth.

Oiling bearings. Fill the front oil cup twice with a good grade of oil. Add ten drops to the rear-bearing oil cup. Add two drops of oil in the hole leading to the breaker bearing.

Comparison of two, four, and six-wing rotor magnetos. Dixie magnetos are made in two, four, and six-wing rotor models. The number of rotor wings determines the maximum number of sparks per revolution of the rotor which can be obtained, provided a cam of the same number

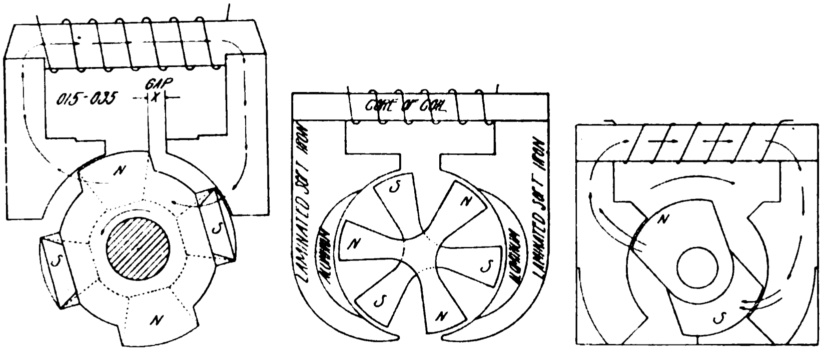

FIG. 463.—Two, four, and six-wing rotors.

of lobes is used. For example, a four wing rotor used in connection with a four-lobe cam gives four sparks per revolution, while the same rotor with a two-lobe cam gives two sparks per revolution. The latter type is called a unidirectional magneto, as the secondary current always flows in the same direction.

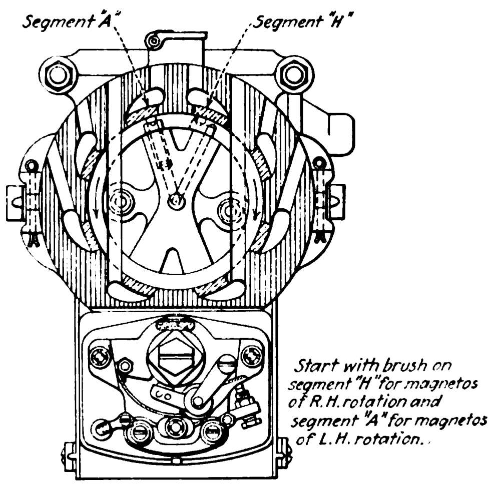

FIG. 464.—Diagram showing relation of high-tension terminals to segments in the distributor of the Dixie 800.

The structure of the field pieces varies with the number of rotor wings, as shown in Fig. 463. In a two-wing rotor magneto, the inner faces of the field pieces are placed at an angle of 180 degees with respect to each

other, while in a four-wing rotor magneto this angle is 90 degrees. In a six-wing rotor magneto, the field pieces are so arranged that four of the rotor wings are in a magnetic contact with the field pieces at one time. This is accomplished without magnetically short-circuiting the rotor wings, by an insert of aluminum in the field pieces, as shown in Fig. 153.

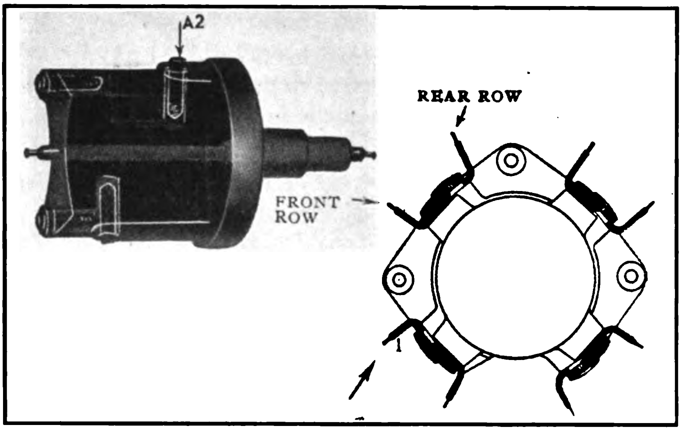

Fig. 465.—Dixie 80 distributor rotor.

256. Operation. Drive the magneto at low speed, about 100 to 150 r.p.m. and note the length of the secondary spark that can be obtained across an adjustable spark gap.

Drive the magneto at high speed, 3,000 r.p.m., and note that the spark will jump a larger gap than at low speed. The position of the

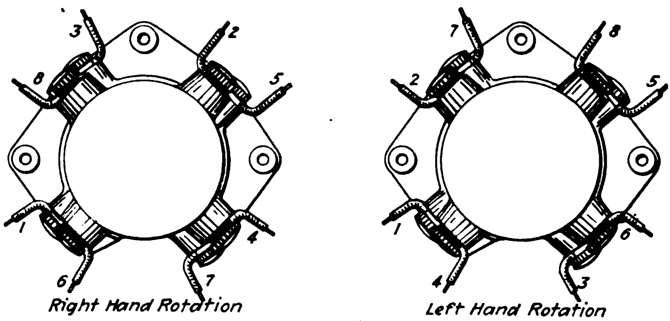

Fig. 466.—Dixie 80 distributor block showing order of firing of the magneto.

timing lever should then be changed. It will be noted that this has no effect on the length of the spark which can be obtained.

The sequence of firing in the Dixie 800 differs somewhat from that of other types used on aircraft engines. In the Dixie 800 it will be noted that the high-tension terminals are not located in the same order as their corresponding segments in the circumference of the distributor.

In some other models of the Dixie it will be found that the distributor rotor has two brushes, one for an inner row of segments and one for an outer row of segments. The sequence of firing will be found to be as in Fig. 466.

As an example of the manner in which the magneto should be wired to the engine, the following table gives the sequence of firing of the Dixie 800 and the cylinder to which each high-tension lead should be attached, as used on the Hispano-Suiza Engine.

TABLE XLIII.—HIGH-TENSION WIRING OF DIXIE 800 TO HISPANO-SUIZA ENGINE

Segment on magneto		Cylinder of engine
A	attached to	1L
B	attached to	4R
C	attached to	2L
D	attached to	3R
E	attached to	4L
F	attached to	1R
G	attached to	3L
H	attached to	2R

Typical Vibrating-coil System.

257. Study of Operating Characteristics. Although the various vibrating-coil systems differ somewhat in design and construction detail, the underlying principle of all these systems is the same.

If the operating characteristics and functions of each part of one system are thoroughly understood it will not be necessary to acquaint the student with these same facts in all the other systems employed at the present time.

In studying the different units employed in a vibrating-coil system, the simple type will be considered.

The induction coil or vibrating coil consists of a core of soft-iron wire, around which is wound a few layers of insulated copper wire which is termed the primary winding.

A great number of layers of very fine insulated copper wire, called the secondary winding, are wound outside of the primary winding.

When a current of electricity flows in the primary winding and is suddenly stopped, a high voltage is induced in the secondary winding which jumps its spark-plug gap and causes a current to flow in the secondary circuit. This secondary current flows in waves and a wave is produced whenever the primary current is stopped by a contact breaker of some sort.

As the secondary current flows only when the primary current is interrupted suddenly, an arrangement must be produced which completes the primary circuit in order that the current from the battery may flow

through the primary, and then breaks the circuit, so that the battery current is interrupted.

This arrangement when operated electrically, is termed a vibrator. The magnetic or electrical vibrator depends upon the magnetism produced in the soft-iron core of the coil when the primary current is flowing.

Referring to Fig. 157, a flat spring, called the vibrator spring or trembler blade is placed so that one end of it is opposite the end of the iron core, and the other end is firmly supported.

This is shown at *D* in Fig. 467. Touching the trembler blade near its free end *N*, is the point of contact with the adjusting screw. One terminal of the battery is connected to the adjusting screw *F*; the vibrator blade *D* is attached to one end of the primary winding of the coil, denoted by *PW*. The other end of the primary is connected to the

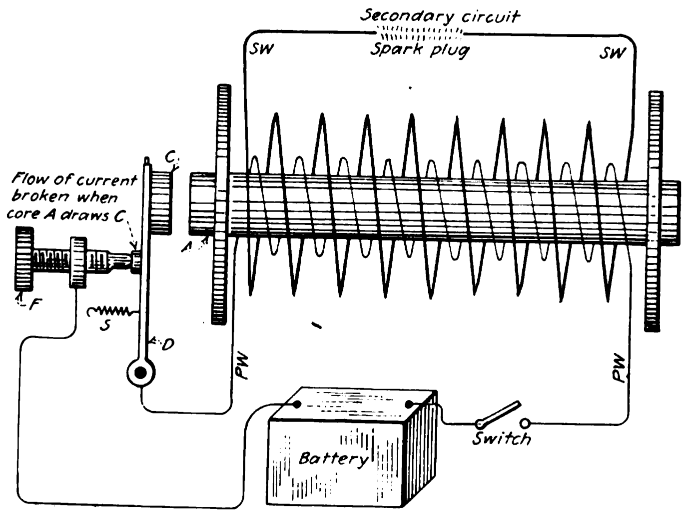

FIG. 467.—Vibrating-coil.

commutator or its equivalent, in this case, the switch at *M*. When the commutator switches the current through the primary winding, the iron core *A* becomes magnetized and attracts the free end of the vibrator blade *C*, drawing it away from the adjusting screw *F*. The magnetic force must be strong enough to overcome the tension in the spring *S*. As soon as the attraction draws the blade *D* out of contact with the adjusting screw, the electric circuit is broken, the current stops flowing in the primary coil, and the core ceases to be a magnet. As the blade is no longer attracted by magnetism it is pulled back by the spring *S* and again makes contact with the adjusting screw. This again closes the circuit, the blade is attracted by the magnetism, and thus the circuit through the vibrator blade and adjusting screw is constantly broken and made again so long as the commutator keeps the primary circuit closed through its contacts.

The strength of the secondary current, and consequently the strength of the spark, depends on the correct adjustment of the vibrator blade by the adjusting screw.

The high-tension coil, using a magnetic vibrator in connection with a commutator, causes a succession of sparks instead of a single spark. This is due to the rapid vibration of the trembler blade.

An ordinary vibrator coil makes several sparks, usually starting before the piston is on the top of the compression and ending considerably after. The spark should occur before top of compression and ignite the charge so that combustion will have time to take place on the top, at the point

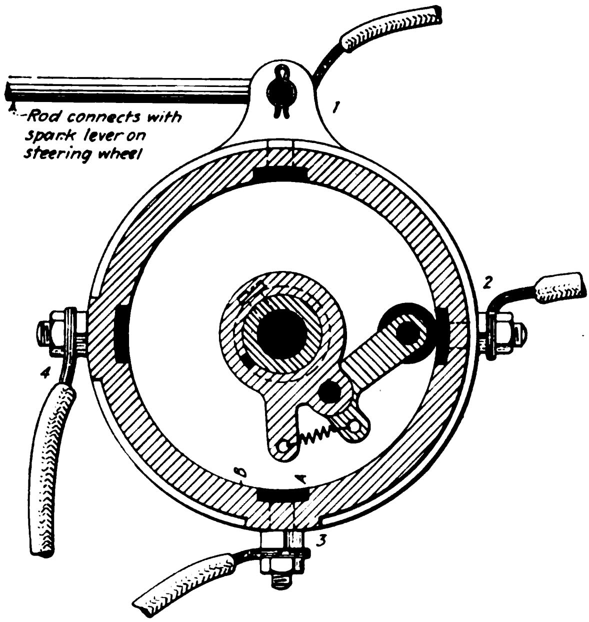

Fig. 468.—Timer or commutator.

of highest compression thereby getting the greatest power from the engine.

The disadvantage of this type of coil is the possibility of the vibrator platinum points sticking, causing a missing of explosions.

Because the secondary current is only needed when it is time for the spark to occur and ignite the charge, the primary current is switched into the primary winding only once during two revolutions, on a single cylinder engine, and the switching is done by a commutator or timer. The device which is always used in connection with a magnetic-vibrator type of coil is that which makes the contact by a brush or roller as illustrated in Fig. 468.

The timer is a mechanical method of causing the contact to be closed and

opened and is generally used in connection with a coil without a vibrator, so will not be dwelt upon in this discussion.

A commutator might be termed a revolving switch which brings two pieces of metal in contact with each other as it revolves.

The metal contacts in the fiber housing to which the wires from the coils are connected, are called segments. These are shown by **1, 2, 3** and **4** in Fig. 468. There are as many segments as there are cylinders. These segments are placed certain distances apart, according to the number of cylinders. For instance, a 2-cylinder commutator would have two contacts spaced 180 degrees apart if it is of the opposed cylinder type. In a single cylinder engine only one spark is necessary during

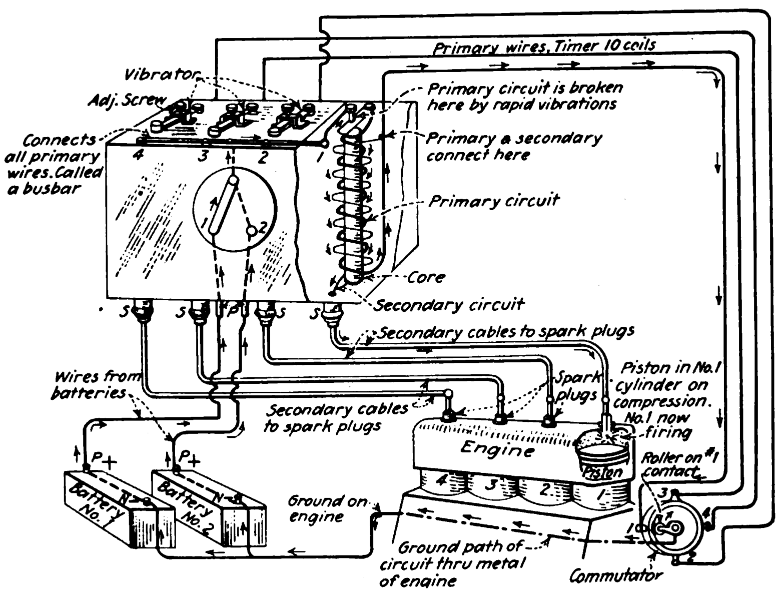

Fig. 469.—Circuit diagram of a vibrating-coil system.

two revolutions of the crankshaft, therefore the contact roller would revolve at one-half the speed of the crankshaft and there would be only one contact segment. In a 4-cylinder engine there would be four contacts placed 90 degrees apart, as shown in Fig. 158. As the contact roller revolves at one-half the speed of the crankshaft, there would be four sparks during two revolutions of the crankshaft.

With the aid of the commutator the operator can either advance or retard the spark to suit conditions of operation. The lever attached to the commutator is shown in Fig. 468.

A typical layout for a vibrator-coil system is shown in Fig. 469.

This illustration will explain the wiring connections from the battery or any other source of current, through the coils and commutator. A

separate coil unit is provided for each cylinder, and the duty of the commutator is to make contact at a certain time, in order that the right coil will operate and supply a spark to the right cylinder at the correct time.

For the wiring connections let us assume a 4-cylinder engine with a firing order of 1–3–4–2. In looking at the commutator in Fig. 469, it is seen that the segments are numbered accordingly. The connection from contact segment No. 1 will lead to No. 1 vibrator coil, the secondary of which will be attached to No. 1 cylinder of the engine. The other three connections will be made in the same order as shown in the diagram.

One other part, which is used in connection with all high-tension coil systems, whether vibrating or non-vibrating, is a condenser.

The purpose of the condenser is to intensify the spark at the plug and also to prevent excessive sparking at the platinum points on the vibrator. If sparking at the vibrator points is permitted to continue they will wear and become pitted and will stick or weld together. The constructional details and operating characteristics of the condenser are explained more fully in another part of the text.

As the primary voltage always remains the same in a vibrating-coil system, operating at high or low speeds has no effect upon the strength of the spark at the plugs. The intensity of the spark at high speed may be a little lower, due to the fact that the magnetic field around the core has not sufficient time to build up to its full value due to the short period of contact between the roller and segment.

Vibrating-coil systems are seldom used at the present time, as the more modern non-vibrating coil systems have several advantages over the vibrating-coil system.

A spark of great intensity is needed in the engine of the present design, due to the high-compression pressures and a good single hot spark is a great improvement over a series of doubtful, weak sparks.

Liberty Ignition System

258. Wiring. All wiring connections as installed on the Liberty ignition system are very simple due to the fact that all terminals are marked for the proper connection.

From the generator proper the terminal marked generator armature is connected by means of a lead to the terminal marked generator armature on the voltage regulator. A like connection is made from the terminal marked generator field on the generator to the same designated terminal on the voltage regulator. The student should bear in mind, therefore, that there are only two connections on the generator.

Two connections have already been made to the voltage regulator, the other terminal on the voltage regulator leading to ground.

From the switch one lead, marked positive battery, goes to the positive

terminal of the battery, the negative side of the battery being grounded. Another lead goes from the terminal marked generator armature on the voltage regulator to the terminal marked generator armature on the switch. The other two connections are from the terminals marked right distributor and left distributor on the switch to the right hand terminals of the respective distributor assemblies on the engine.

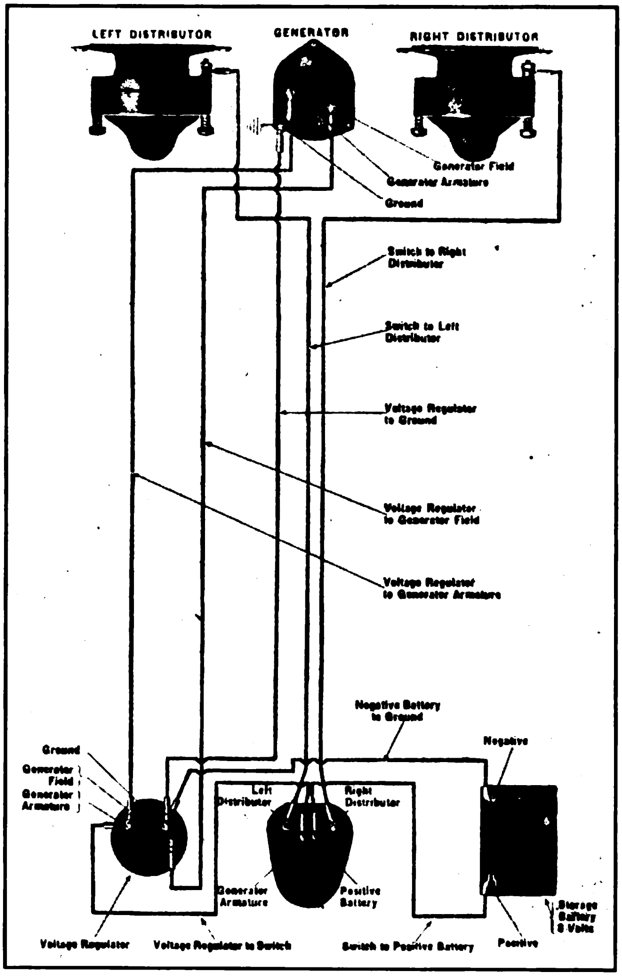

FIG. 470.—Wiring diagram of Liberty ignition system.

All of the connections as described above are shown in Fig. 470. All of the high-tension leads are carried in two manifolds made of pressed steel. A Kerite rubber-covered cable having 19 strands of No. 26 copper wire has been used to a large extent for the high-tension wiring. The rubber insulation is $\frac{5}{64}$ in. in thickness and the outside diameter of the wire is $\frac{5}{16}$ in.

Ninety-three feet of cable are needed to make the 24 lengths, cut as shown in the following table:

TABLE XLIV.—CABLE LENGTHS FROM DISTRIBUTORS

Cable	Cable length	
	From left distributor	From right distributor
To 1L	2 ft. 2 in.	2 ft. 8 in.
To 1R	2 ft. 3 in.	2 ft. 8 in.
To 2L	2 ft. 9 in.	3 ft. 2 in.
To 2R	2 ft. 7 in.	3 ft. 5 in.
To 3L	2 ft. 10 in.	4 ft. 1 in.
To 3R	3 ft. 7 in.	3 ft. 6 in.
To 4L	4 ft. 2 in.	4 ft. 2 in.
To 4R	3 ft. 8 in.	4 ft. 6 in.
To 5L	4 ft. 3 in.	5 ft. 2 in.
To 5R	4 ft. 10 in.	4 ft. 9 in.
To 6L	4 ft. 10 in.	5 ft. 7 in.
To 6R	5 ft. 0 in.	5 ft. 6 in.

The high-tension insulation is cut back about 1 in. on the distributor ends of the leads and about ½ in. on the spark-plug ends. The terminals at the spark-plug ends are slipped over the cable so that the copper wires extend through the hole in the end of the terminal about ¼ in. The wires may then be spread and securely soldered to the terminals.

All high-tension leads should be checked at this stage of the assembly and the distributor ends placed in the proper hole in the two high-tension cable separators. A metal sleeve is placed over the wire at the distributor end and is forced between the rubber insulator and wire for a depth of ½ in. A soft-rubber sleeve is placed over the rubber insulation to give added protection to the cable end. The sleeve and wire are then bent in the form of an eye and the sleeve is filled with solder to make a good tight joint between the sleeve and wire. All terminals must protrude at least 6½ in. beyond the manifold at the spark-plug ends.

All low-tension wire should be of No. 14 stranded cable for a distance of 10 ft. or less and No. 10 for distances up to 25 ft. These cables should be well insulated with rubber or rubber and braid. All wires should be fastened at frequent intervals to the fuselage by clips of wood, fiber or webbing. Wherever the wire is exposed to oil it should be taped and well shellacked under the clips. All low-tension cables should be attached with cast nuts and well cottered.

259. Operation. In tracing the circuit diagram we will assume that the right switch is turned to the *on* position. The current will flow from the battery to the battery terminal of the switch, through the ammeter,

right switch and current-limiting resistance unit to the right terminal of the right distributor assembly. From the right distributor terminal the current will flow through the primary coil to the breaker contacts, and from there to the ground. When the breaker points open a high voltage will be induced in the secondary coil. At the same time the distributor-rotor brush will make contact with the distributor segment which is connected by the high-tension cable to the spark plug.

When the left-hand switch is turned to the *on* position, the right switch being in the *off* position, the current will flow through the left-hand switch to the left-hand distributor assembly along a similar path, as in the case explained before.

When both switches are turned to the *on* position, which should never happen until the motor is turning over at least 750 r.p.m. crankshaft speed, the generator is connected in the circuit. The generator current will flow to the generator terminal on the switch and from here across the left switch and over to the right switch. In the right switch the current will divide into three paths. Part will flow to the right distributor assembly, part to the left distributor assembly, and part through the ammeter and charge the battery.

In starting the engine one switch only should be thrown to the *on* position, thus supplying the current for single ignition from the battery. During the time the engine is being warmed up the two switches can be used singly in order to test out both sets of plugs. When the engine is warmed up and the speed exceeds 750 r.p.m. both switches should be thrown on so that the current used will be furnished by the generator.

If both switches are thrown on at low speeds the battery will immediately discharge back through the generator at an excessive rate which will probably injure it.

At speeds below 750 r.p.m. the voltage of the generator is lower than that of the battery. As the generator speeds up its voltage increases, and when the engine speed is above 750 r.p.m., the generator voltage is higher than that of the battery. Under that condition, if both switches are thrown on, the generator will charge the battery in addition to supplying the ignition current. The rate at which the battery will be charged will depend upon its condition.

With a practically discharged battery the rate will be about 10 to 15 amperes but will diminish as the battery voltage rises until the battery is completely charged, when the charging rate will be just sufficient to maintain it in a properly charged condition.

The generator voltage is controlled by a voltage regulator which prevents the voltage exceeding a predetermined figure, usually around 10 volts. The spring in the regulator controls the generator voltage and when this spring is once adjusted it should not be tampered with.

The adjustments have to be made by men thoroughly familiar with the apparatus.

The ignition switch includes an ammeter and this ammeter should be watched occasionally as it indicates the amount of current flowing to or from the storage battery.

If the ammeter shows a discharge at any speed above 750 r.p.m. with both switches *on*, it is an indication that something is wrong with the system and that all electrical energy is being supplied by the storage battery. If the ammeter stands at zero under the same conditions it indicates that the storage battery is not receiving a charge, but that the ignition is being carried by the generator.

There are two distributor assemblies which are independent of each other, the left distributor operating the rear plugs and the right distributor operating the propeller plugs.

260. Ignition Timing. In the following procedure it is assumed that the two main breakers in each head have already been timed with respect to each other. The method by which this is done will be discussed under "Construction and Adjustments."

Single ignition. The most convenient method of timing is by use of a timing disk which is used in the following manner. If the timing disk is not already mounted on the propeller flange the propeller must be removed and the timing disk clamped to the propeller-hub flange by two bolts through the propeller-bolt holes. (1) Remove the spark plug from the propeller side of No. 6L cylinder. (2) Insert a rod or scale through the spark-plug hole and turn the engine over by means of a propeller-hub wrench until the piston on its up stroke with the exhaust valve closing, touches the rod and causes it to ride up. Continue to turn the engine over slowly until the piston as indicated by the travel of the rod stops moving upward and is just about to start down. This will be approximately the top dead center. Allow the crankshaft to remain in this position temporarily and clamp the timing pointers under the special cylinder-base flange nuts so that the pointers extend over the timing disk. (3) With the end of the rod resting on the top of the piston, make a mark with a file about ½ in. above the edge of the spark-plug hole. (4) Turn the engine over in a forward direction until the rod has moved down so that the mark is even with the edge of the spark-plug hole and with a piece of chalk or a pencil mark the disk in line with one of the pointers. (5) Turn the engine backward until the rod has moved up and down to the point where the mark is again even with the edge of the spark-plug hole and mark the disk in line with the pointer. (6) With a pair of dividers find the point midway between the two marks on the disk. This point will be the exact top dead center of No. 1 and No. 6 cranks and should be marked with chalk or a pencil. (7) Turn the engine until this dead-center mark is in line with the pointer. Allow

the crankshaft to remain in this position. (8) Reset the pointers so that they come in line with the dead-center marks stamped on the disk. (9) Turn the engine in the direction of rotation through 10 degrees as indicated by the scale on the disk. The crank is now set at the neutral point of No. 6L, and the firing point, spark retarded, of No. 1L.

Another method of finding the dead center and firing point if no timing disk is provided, is by use of the marks on the back of the propeller-hub flange in connection with two sets, one for each cylinder bank, of punch marks on the crankcase. The propeller-hub flange has three

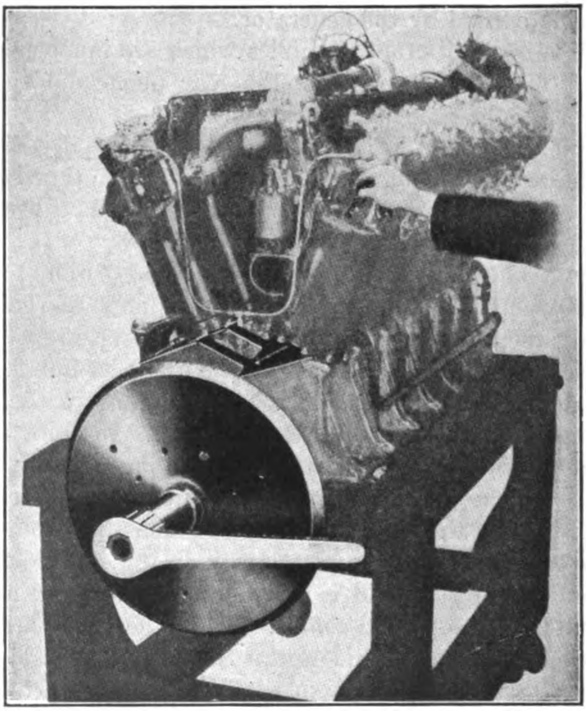

FIG. 471.—Use of timing disk.

sets of marks $\underset{1:6}{T:C}$, $\underset{2:5}{T:C}$ and $\underset{3:4}{T:C}$ with an arrow to show direction of rotation. Ten degrees behind each top center mark is another mark to show the neutral point and retard firing point of that pair of crank-throws.

Remove the propeller and with a combination square and scale, set the neutral-point mark for cylinders No. 1 and 6L with No. 1L in the firing position. The engine is now on the neutral point of No. 6L cylinder and the firing point, spark retarded, of No. 1L cylinder.

(10) Connect a test lamp from the positive of the battery in series

with the low-tension terminal of each distributor assembly. Ground the negative terminal of the battery to the engine. (11) Move the timing

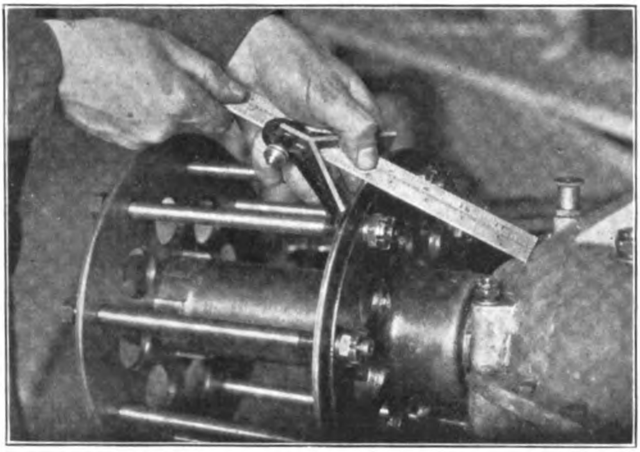

FIG. 472.—Use of combination square.

lever on the left-distributor assembly to the full retard position, that is, as far in a clockwise direction as is possible. (12) Loosen the bolts holding the distributor assembly to the camshaft housing and move the distributor-adapter base until the lamp just goes out. (13) Tighten the two bolts with the distributor assembly in this position and install the remaining four bolts.

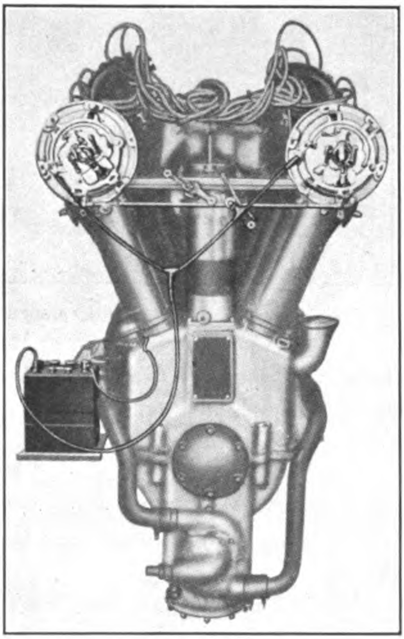

FIG. 473.—Lamp connections for synchronizing the distributor assemblies.

Double ignition. (14) Without changing the position of the crankshaft, set the right-distributor assembly in a similar manner to that of the left-distributor assembly.

(15) The accuracy of the timing should now be checked by rotating the engine through two complete revolutions very slowly, at the same time watching the lamps light and go out. The two lamps will not go out at the same time on each firing point, due to the slight irregularities of the cam. Hence it may be necessary to adjust the right-distributor assembly slightly to obtain the best

average. (16) Install the tie rod with both distributor assemblies in the full retard position. (17) Check the synchronization of the two distributor assemblies with the timing lever in the advance position. (18) Remove the timing disk and replace the propeller.

261. Construction and Adjustments. *Distributor assembly.* The distributor assembly in the Liberty ignition system is divided into three main subassemblies, namely: the distributor-head assembly, the distributor-cup assembly and the distributor-adapter base.

The head is made of bakelite, a compound formed by the action of carbolic acid on formaldehyde, with wood pulp added for strength and pigment for color. A hard-rubber rotor track which contains the metal

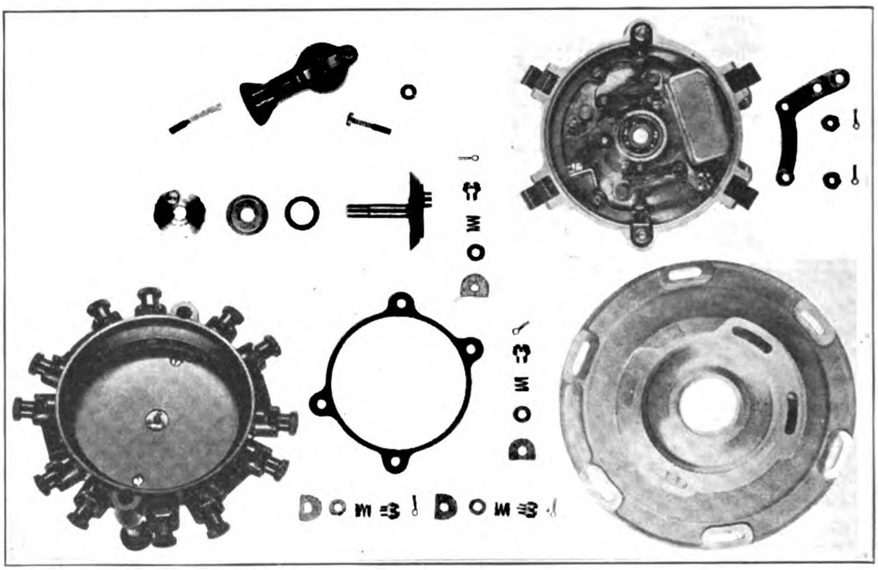

FIG. 474.—Exploded view of Liberty distributor.

contact segments, is placed in a hardened tool-steel die. The crown of the mold is then filled with a sheet of bakelite and the rest of the mold filled with powder.

The mold is then subjected to a hydraulic pressure and at the same time treated with steam for seven minutes.
It is cured for five minutes and then chilled by running cold water around the die.

When the head is removed from the die all burrs and unnecessary projections are buffed and the rotor track is ground to the correct size.

The rubber rotor track is then put in place and the whole cooked for 25 minutes. It is then cured and hardened in a soap-stone bath. The black or brown color is obtained by putting the head in a bath of kerosene.

The primary winding which consists of 151 turns of No. 21 enameled copper wire, having a resistance of 0.31 ohms at 70° F., is wound around a soft-iron wire core. The winding is wound with adhesive tape and slipped into a cardboard sleeve. Insulation material is wrapped around the core under the primary winding.

The secondary winding, consisting of 14,000 turns of No. 38 enameled copper wire, having a resistance of 3,300 ohms at 70° F. is wrapped around the cardboard sleeve. Insulating paper is placed between the layers and the whole is wrapped with empire cloth and impregnated with an insulating varnish.

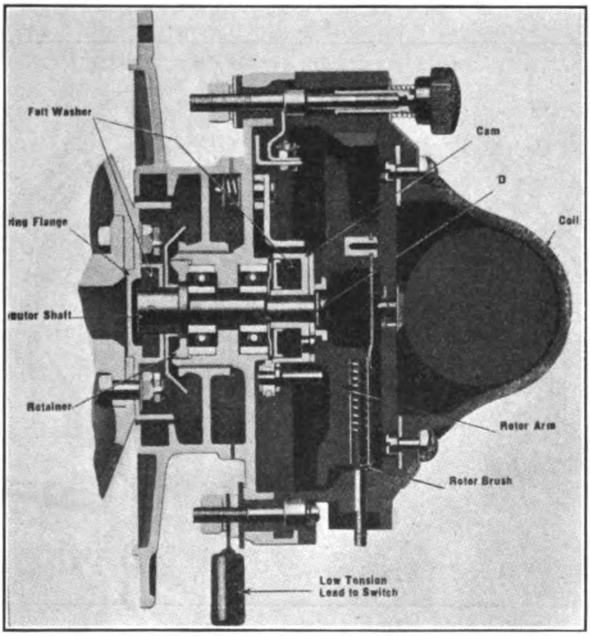

Fig. 475.—Section of Liberty distributor assembly.

The spark is prevented from jumping to ground from the secondary by using bakelite end pieces. End pieces of soft-iron are used both as a supporting structure for the coil and to decrease the reluctance of the flux path. A metal bushing is placed at each end and the assembly is held together by ⅛-in. bolt, driven through the core and fastened with a soldered nut at each end.

The coil assembly is placed in the head so that the end from which the two leads extend is at the bottom of the head. The top of the head is indicated by lettering on the crown. The coil base is fastened to the head with bakelite cement. The base with the attached coil can be removed by softening the bakelite cement with a little acetone. This dissolves the cement but does not injure the bakelite or hard rubber.

The bakelite head is attached to the distributor-cup assembly by means of two terminal studs and four spring clips.

The secondary winding is connected to the rotor-arm spring by means of a small carbon plug inserted in the center of the coil base.

The distributor-cup assembly contains the two main breakers, each performing the same function at the same time for reliability. They also minimize any effects due to possible chatter.

As a safety factor, an auxiliary contact arm is used. This opens about 7 degrees before the main breakers on correct rotation and remains closed 7 degrees after the main breakers open if the engine is rotated in the reverse direction.

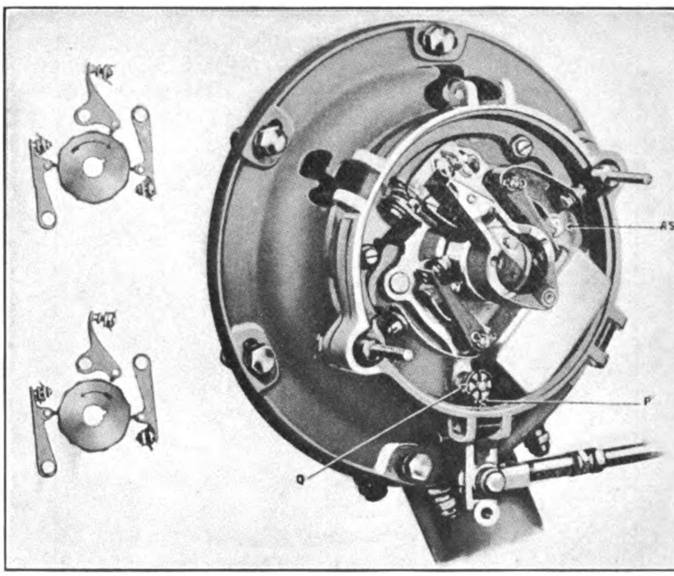

FIG. 476—Liberty distributor cup, assembly, cam and breakers.

The auxiliary breaker is connected in series with a resistance unit of 8 ohms. This is advance metal wire and is wound on a small porcelain spool. The auxiliary breaker is in parallel with the two main breakers. When the engine is rotated in the correct direction, the opening of the auxiliary breaker, which occurs first, produces no spark because the current continues to flow in its full value through the main breakers. When the main breakers open a spark is produced.

When the engine is turned in a backward direction the two main breakers open first and no spark is produced, due to the fact that the current continues to flow through the coil through the auxiliary breaker, but in diminished quantity, due to the resistance unit. By the time the circuit is opened at the auxiliary breaker the intensity of the magnetic

field of the coil has weakened to such an extent that no spark is produced. Fig. 476 shows the relative positions of the three breakers used in the distributor-cup assembly.

The cam is machined from solid-steel stock. It has six long and six short lobes. There is an angle of 45 degrees between the banks of cylinders on the Liberty 12 engine, and it fires 45 and 75 degrees apart. Since the cam has 12 lobes it will complete one revolution when the crankshaft has completed two. Therefore the cam lobes should be spaced 22½ degrees and 37½ degrees. With this arrangement the breaker points would remain closed longer for some lobes than for the others. At high speeds this would allow the primary current to build up to a higher value on every other lobe so that one bank of cylinders would receive a better spark than the other bank.

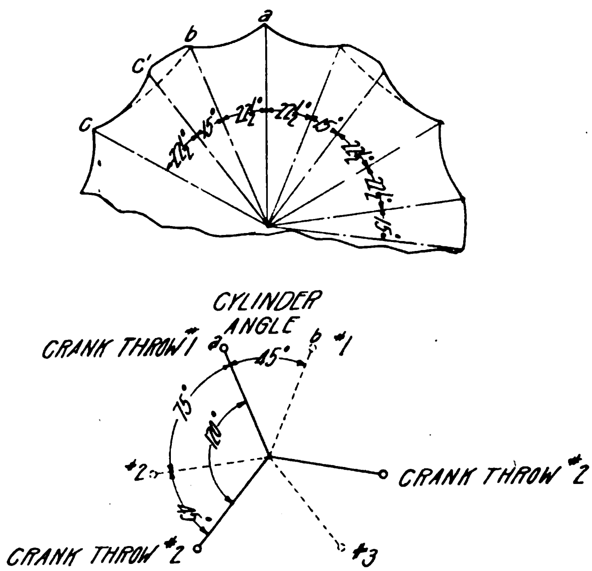

Fig. 477.—The Liberty cam.

In order to make the interval of closing the same for all lobes, every second lobe is made 15 degrees long so that the breakers will be held open during this period.

This design will allow the breakers to be closed the same length of time before every break and a spark of the same intensity is assured for every lobe.

The cam is ground on the outside, case-hardened in a bath of cyanide and polished with crocus. The inside is hollowed out and filled with felt washers which are saturated with oil. Small holes are drilled in the face of the cam so that the oil from the felt washers will be thrown out by the centrifugal force and lubricate the face of the cam. At the present

time the cam is ground to a master cam six times the desired size. The cam is then checked with a protractor so that the breakers must open with a variation either way of not over 1½ degrees.

A small hole is drilled into the rotor arm through which the felt washers can be oiled. A good grade of gun oil or machine oil should be used for the oiling of the cam face.

The Liberty condenser consists of tinfoil between which are sheets of paraffined paper. The condenser assembly consists of two separate condensers connected in parallel for reliability. These are sealed in a metal housing. If either condenser should become open or develop a slight leak the other is large enough to keep the system in operation. If either, however, should develop a short-circuit the primary current would not be broken and the system would become inoperative.

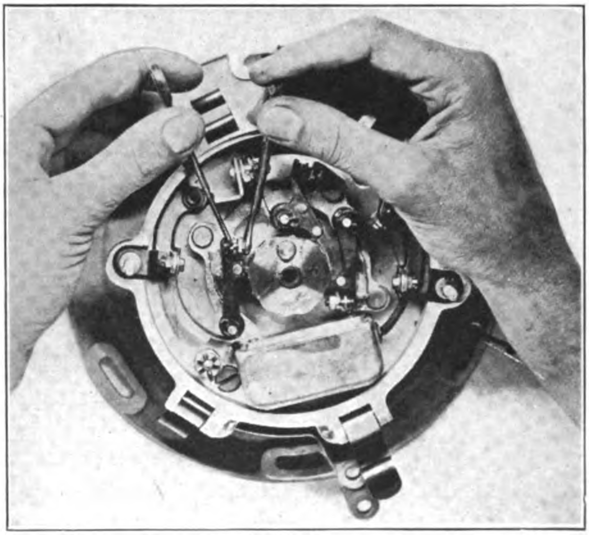

FIG. 478.—Adjustment of the Liberty breaker contact gap.

The condenser and breaker yoke assembly is supported upon four studs which extend out from the distributor cup. The stud nearest the condenser passes through a round hole and acts as a pivot while the other studs pass through elliptical holes so that the condenser breaker plate can be shifted slightly in an arc. This permits synchronization of the two main breakers which must break within one degree of each other. The fourth stud is provided with a castle nut in order that the condenser-breaker plate can be locked securely in place.

The fixed contact points are supported on flanges of the condenser-breaker plate which is grounded.

The two main breakers should open simultaneously with an allowable

variation of one degree. The contact separation, when the contact is open, should be from .01 to .015 in. and the spring tension, when the contact is open, should be from 26 to 30 oz. The auxiliary-breaker contact separation should be from .01 to .015 in. when open and the spring tension from 16 to 20 oz. The distributor-cup assembly should rotate with from 2 to 4 lb. pull for timing adjustment. The rotor brush should extend $5/32$ to $7/32$ in. from the rotor face.

A brass gasket is placed between the distributor-adapter base and distributor-cup assembly, to reduce friction. The distributor-cup assembly is attached to the adapter base by means of four bolts. A spring is put under the head of each bolt to keep the proper tension and yet permit

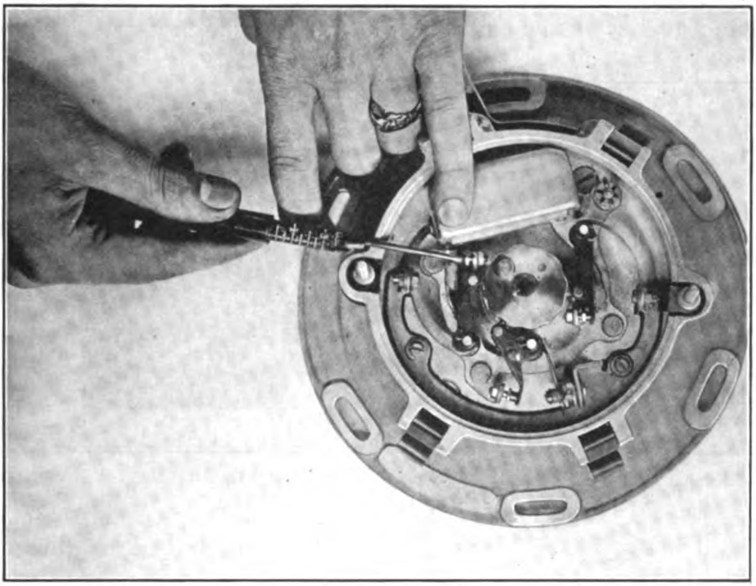

FIG. 479.—Adjustment of Liberty breaker—spring tension.

the cup to be rotated. The nuts should be tightened until it requires from 2 to 4 lb. on the timing lever to move the distributor from advance to retard.

If the two main breakers do not open simultaneously, the nut which holds the condenser breaker-plate assembly should be loosened and the plate shifted until the two main breakers operate correctly at the same time. To do this one main-breaker spring must be insulated from the terminal-connector plate. A connection is made from the positive terminal of the battery through an 8-volt lamp to each main breaker spring. See Fig. 480.

The breaker plate is adjusted until both lamps go out together and, when this adjustment is obtained the lock-nut is tightened. In adjust-

ing the breaker plate the contact openings will probably be thrown out of adjustments since the condenser-breaker plate does not rotate around the distributor shaft as a center. This will necessitate a readjustment of the contact gaps and a rechecking of the breaker opening until the main breakers operate in synchronism and the contact gaps have the proper opening.

The distributor-adapter base is machined from aluminum and serves as a supporting structure for the distributor-cup assembly. There are six slotted holes in the flange of the adaptor base, which permit the shifting of the assembly to synchronize the two heads. There are also four slotted holes in the distributor-cup flange which permit a 20-degree movement of the distributor assembly, thus providing the necessary 40-degree range of advance on the engine.

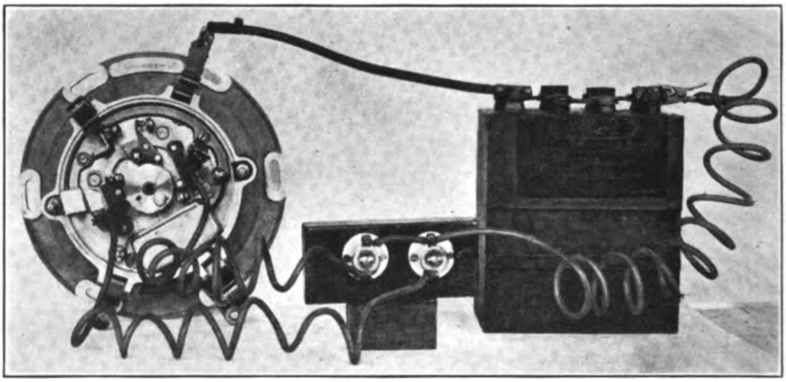

FIG. 480.—Electrical connections for synchronizing two main breakers on liberty distributor assembly.

The distributors are marked R and L on the outside surface of the spark-control arms. They should be fastened temporarily by means of two bolts, each in such a position that the notch on the distributor-base flange coincides with the notch on the camshaft housing flange.

If it has been found necessary to replace either the camshaft housing or the distributor head, and the new parts do not carry these identifying notches, the distributor should be set so that, with the spark retarded the center line of the cylinders will be midway between 1L and 6R terminals.

Voltage regulator. The voltage regulator consists of an iron core on which are wound three coils, namely, the voltage coil, reverse winding, and non-inductive winding. The connections of these are illustrated in Fig. 481. The voltage coil has a resistance of 39.6 ohms, the reverse coil a resistance of 115 ohms and the non-inductive winding, 44 ohms.

The voltage and reverse coils are both wound in the same direction, but the current through the reverse coil flows in the opposite direction

to that through the voltage coil so the reverse coil tends to wipe out some of the magnetism produced by the voltage coil.

The non-inductive coil is constructed in a special way by doubling the wire before winding to remove the inductive effect.

The frame of the regulator carries a pivoted armature fitted with adjustable contact points at one end. The contact points are normally

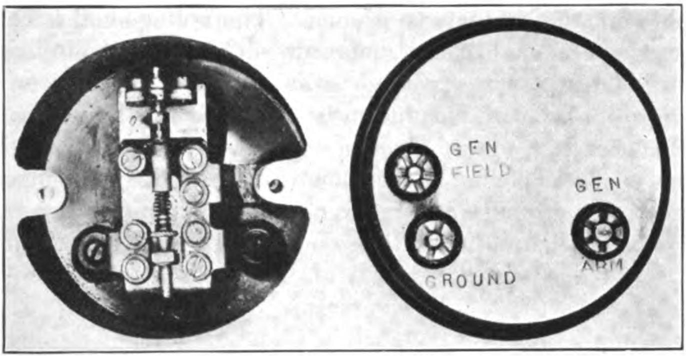

FIG. 481.—Liberty voltage regulator. Arrangement of elements and diagram of connections.

held together by an adjustable spring. This is shown at 6 in Fig. 481. The regulator will need practically no attention, with the exception of adjusting the spring tension and an occasional checking up of the contact separation and the length of the brass pin set into the opposite end of the

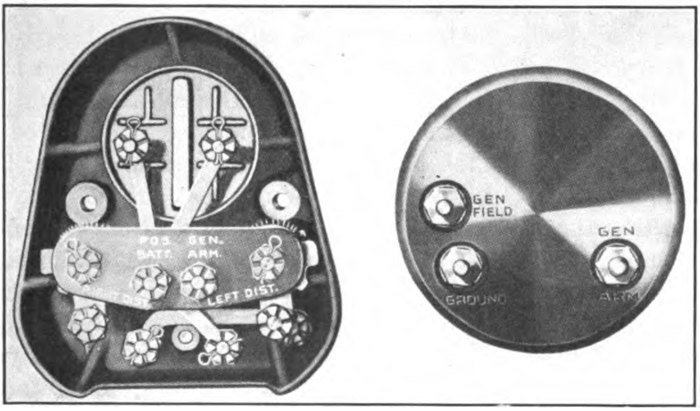

FIG. 482.—Liberty voltage regulator.

armature. This pin should extend from .043 to .045 in. above the surface of the armature. When the armature is pressed down so that this pin bears against the end of the core the gap between the contact points should be from .005 to .007 in. In adjusting the spring tension the gener-

ator should be driven at 3,000 r.p.m. with no load and the spring tension should be adjusted to give a generator voltage of 10 volts at the terminals.

The operation of the regulator is as follows: The field current flows from the positive terminal of the generator through the generator field to the field terminal of the regulator. From there it can take three paths as shown by Fig. 171. It will take the path of least resistance and go through the contacts to ground. The voltage coil is connected to the positive terminal of the generator. Therefore, the full generator voltage will be across the voltage coil. When the generator voltage reaches 10 volts the core is sufficiently energized by the voltage coil to attract the armature, overcoming the tension of the spring, and opening the contacts. The opening of the contacts cuts off the field current from going directly to ground and it now has to go through the reverse coil and non-inductive winding. Resistance is added to the field circuit here and thus the field strength is lowered. As a result, the voltage will decrease when the points are opened.

The action of the reverse coil is to wipe out some of the magnetism in the core so that the voltage has to fall only a slight amount before the points will be closed again by the spring tension. This action occurs so rapidly that the armature vibrates at a high rate and the voltage is maintained practically constant.

The voltage regulator is attached directly to the back of the switch by means of two long studs. There are three external connections, namely: generator armature, generator field, and ground.

Generator. The Liberty generator is a shunt wound, self-excited, 4-pole machine. The armature is wave wound. Although only two brushes are needed, four are used for reliability. Each brush has sufficient cross-section to carry the current, so if one brush should fail the generator would still function properly. The current delivered by the generator depends upon the battery condition and may vary from 15 amperes down. It is designed to carry 5 amperes continuously. Owing to the fact that the armature is impregnated with Sterling varnish, it can stand a temperature of between 150° F. and 200° F. without injury.

The armature-circuit resistance, with the brushes, is .41 ohms at 175° F.; the shunt-field resistance, 3.81 ohms at 75° F. and 4.5 ohms at 175° F. It should require a force of 16 to 20 oz. to raise a brush from the commutator. There is one thrust and radial bearing in the top of the generator which supports the weight of the armature. The speed of the generator is one and one-half times the speed of the crankshaft.

Switch. The current in the Liberty ignition system is controlled by means of two interconnecting switches. Either switch lever, when used alone, causes the battery to supply current for single ignition. When both switches are turned to the *on* position the generator is connected

in the circuit to furnish the current for double ignition, and at the same time to charge the battery.

The switch assembly consists of a base, two switches, two current-limiting resistance units, an ammeter and the terminal connectors. The base of the switch is molded from black bakelite with metal inserts for switch-contact points and terminal-connector supports. The skirt of the bakelite base forms a protective covering for the ammeter, resistance units and terminal-connector structure. The switch-contact arms are punched from thin phosphor bronze and are laminated to give a greater elasticity. The ignition-switch cover is stamped from sheet metal, nickel plated and then enameled. The resistance units are spirals of No. 23 advance metal wire, having a resistance of 1 ohm each. These are supported upon porcelain spools.

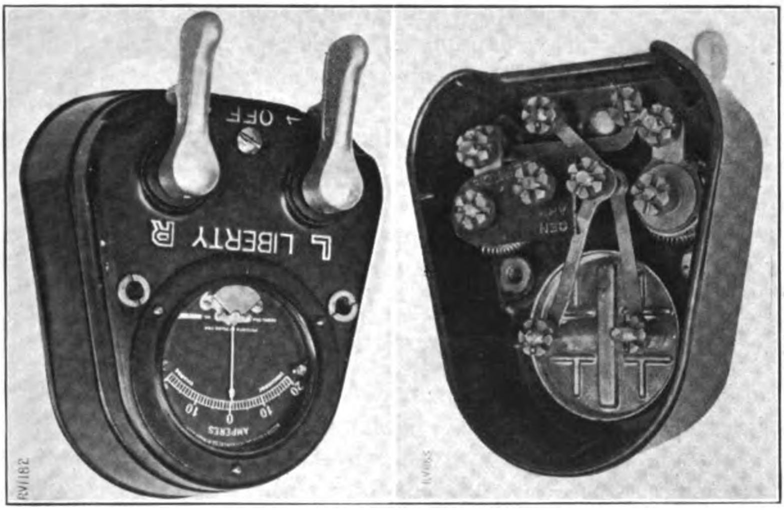

FIG. 483.—Front and rear view of Liberty switch assembly.

The left-hand switch has four metal contact points arranged in a square, while the right has three. The outside upper contacts extend through the base and form supporting studs upon which the resistance units are placed, and which also support the bakelite insulator plate across the terminals. The right-hand upper contact of the left switch projects through the base and terminal-insulator plate and forms the generator-armature terminal of the switch assembly. The lower left contact of the left switch, as viewed from the front, is connected to the lower contact of the right switch by a terminal connector of nickel-plated brass. The lower right contact of the left switch is connected to the upper left contact of the right switch, and also to the right ammeter terminal, by a similar terminal connector. A third terminal connector

extends from the positive-battery terminal, on the terminal-insulator plate, to the left ammeter terminal.

The left switch-handle stud is unlike the right in respect to the relative position of the lug on the side of the stud to the tapered hole. When the lug on the left stud is pointing to the lower left contact and the lug on the right is pointing to the lower right contact recess, the tapered holes should be in a vertical position with the larger end up. The switch handles and tapered screws are not interchangeable and must be replaced if the switch-handle studs are replaced. The left switch handle and stud are put in place and secured with the switch-lever screw. The right-hand switch handle and stud are assembled in the same manner. In the left switch there are four bronze contact-arm punchings, each having two fingers.

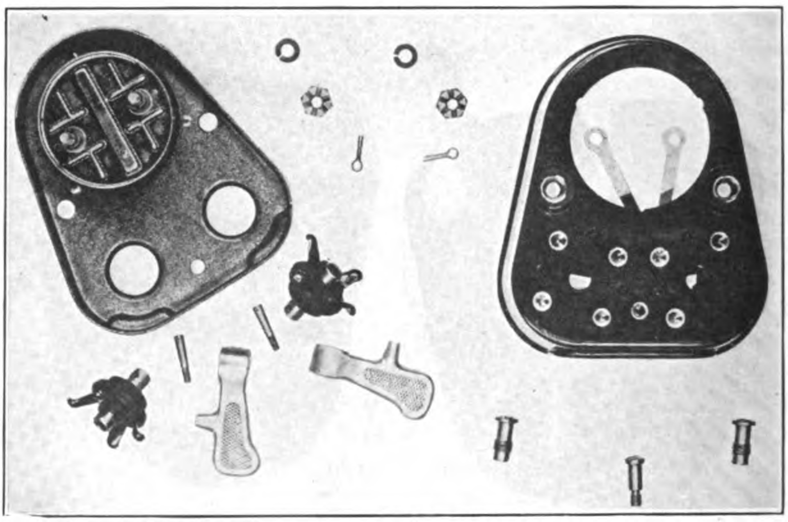

FIG. 484.—Exploded view of Liberty switch.

The two upper contact arms, contact insulator and lower contact arms, are put in place on the left-hand switch stud. There are only two contact arms in the right switch, each having four fingers. Unlike the left switch assembly, these are not insulated from each other when assembled on the right switch-handle stud. The base is placed on the switch-cover assembly and secured with two side-cover screws and a center cover screw. The various terminal connectors are fastened to their proper studs by castle nuts which are lock-washered and cottered. The resistance units may then be placed on the studs projecting from the back of the upper contacts in each switch with the distributor terminal below the insulator plate, so that the metal lug on the side of the unit presses against the skirt of the base to prevent the unit from turning. The bakelite terminal-insulator plate is placed over the two studs supporting

the resistance units, and the third stud which forms the generator-armature terminal. The terminal plate is secured with the resistance unit nuts which are cottered.

The function of the left switch, when operated alone, is to complete the circuit from the battery to the left distributor assembly and thus fire the propeller spark plugs in each cylinder. The function of the right switch, in a similar manner, is to complete the circuit from the battery to the right distributor which frees the front set of plugs. When both switches are thrown to the *on* position, the generator furnishes current for both distributor assemblies firing both sets of plugs and at the same time charging the battery. The object of the resistance unit is to limit the current flowing through the primary coil. These resistance units should be examined to see that the turns do not come into contact with one another, thereby reducing the resistance of the unit. The purpose of the ammeter is to show the amount of current flowing to or from the battery, thus giving some indication as to whether or not the system is functioning properly.

After the switch has been assembled it should be given a mechanical inspection to see that all screws are tightened, nuts and lock-washers are in the proper place, and that all cotterkeys are spread. The terminal connectors should be inspected for short-circuits and the switch levers tried to see that they are not too tight or too loose and have the proper snap to them.

Liberty Generator Troubles

262. Measurement of Field and Armature Resistance. Many troubles which may occur in a generator will affect the resistance of the armature or field circuits. Therefore, it is of value to know how to measure these resistances as a test for locating trouble.

In the measurement of the field resistance the apparatus is to be connected as shown in Fig. 175. The current in the field circuit, as read by the ammeter, is to be adjusted to 1.75 after the voltmeter leads have been connected across the field as shown in Fig. 485. The readings must be taken very quickly as the normal field current will cause the temperature of the field winding to increase very rapidly which in turn will increase the resistance. Before opening the field circuit the voltmeter leads should be disconnected, as the inductive kick, due to the energy stored in the field, may cause a high voltage when the switch is opened. This high voltage will cause the voltmeter needle to deflect beyond the scale and possibly damage the instrument. The readings are recorded as shown in the log, Fig. 486.

In measuring the armature resistance, connections are to be made as shown in Fig. 485. The current should be adjusted to 1 amp. and readings taken of current and voltage. The voltmeter should be removed

before the circuit is opened. Two similar sets of readings are to be taken with armature current of 5 amp. 10 amp. Typical results are shown in the log, Fig. 486.

After all the readings have been recorded and corrected for instrument constants, the resistance values are calculated by means of the relation $R = \frac{E}{I}$. A typical set of results is shown in Fig. 486.

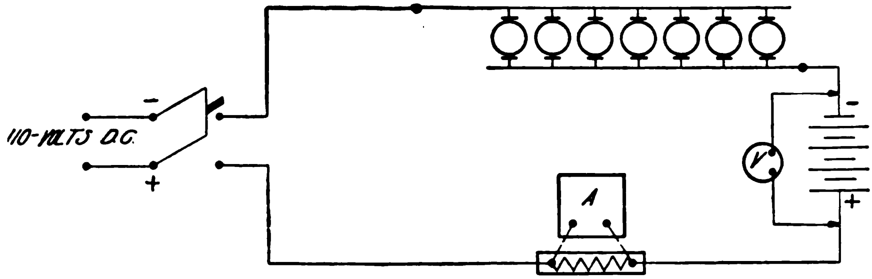

FIG. 485.—Diagram of connections for resistance measurements.

As seen from the last column in the log, Fig. 486, the resistance of the armature decreases with increased current. This is due to the fact that the resistance of the carbon brushes and the contact resistance between the brush faces and the commutator both decrease with increased current. Thus, to speak of the resistance of the armature circuit means

PART OF GENERATOR MEASURED	CURRENT		VOLTAGE		RESISTANCE
	AS READ	TRUE	AS READ	TRUE	CALCULATED $R=\frac{E}{I}$
	K = ÷10		K = ÷2		
Field Winding	17.5	1.75	12.3	6.65	3.80
			K = ÷10		
Armature Circuit	10.0	1.00	5.1	0.51	0.51
	K = ÷2				
do	10.0	5.0	23.5	2.35	0.47
			K = ÷2		
do	20.0	10.0	9.2	4.6	0.46

FIG. 486.—Log of resistance measurements.

very little unless the current, at which the resistance is measured, is specified.

263. Location of Field Circuit Troubles. Under field circuit troubles are grounds open-circuits and short-circuits. A ground in the Liberty field coil will cut out the regulator and will also cause part of the field winding to be short circuited. The effect on the generator cannot be predicted as it will depend upon the location of the ground. Cutting

out the regulator will cause the voltage to rise with speed, but short circuiting part of the field winding will tend to give a lower voltage than normal. Which effect will predominate depends upon the location of the ground and how much of the field winding is short-circuited. Abnormal heating of that portion of the field winding between the positive brush and ground will also occur and this part of the field winding may also burn out.

To test for a ground in the field circuit connections are made as shown in *a*, Fig. 487 (*a*). A voltmeter could be used in place of the lamp shown in Fig. 487 (*a*), and is preferable under conditions which will be discussed later. Since one side of the power line is grounded, a ground anywhere in the field circuit will complete the circuit through the lamp or voltmeter, and cause the lamp to burn or the voltmeter needle to be deflected.

Before grounding one side of the power line, it should be ascertained whether the system is an ungrounded or a grounded system and if the latter whether or not there is any connection between the ground side of the system and the frame of the machine under test. Under the latter conditions, were the ungrounded side of the line grounded to the frame of the machine under test, a short-circuit would result. To avoid this trouble one lead should be fastened to the machine frame and the other lamp or voltmeter lead tapped on each line terminal. Should the lamp burn or voltmeter deflect on either power line under this test, it would show that the other power line was grounded elsewhere and also connected to the machine frame. In this case the grounded side of the line and not the ungrounded side should be grounded to the frame of the machine.

After this test has been made, the positive armature brushes are raised from the commutator and insulated from it by means of cardboard strips. By referring to Fig. 487 it can be seen that insulating the positive brushes from the commutator opens the connection between the field circuit and the grounded negative armature terminal. Now one lead is placed in contact with one of the field terminals, and, if there is a ground in this circuit, the lamp will burn or the voltmeter will show a deflection. Both before and after using the lamp to test the field windings for grounds both leads should be tapped on the machine frame to ascertain whether the lamp is in good condition.

On large machines it is possible to disconnect each field coil from all of the others and test each one separately. On the Liberty generator this is not done. If there is a ground in the field winding the defective field coils are replaced by four new ones. It may happen that the ground is in such a place that it can be insulated by means of a piece of rubber tape, in which case it is not necessary to replace the coils, provided a test after repair showed the ground to have been removed.

A voltmeter gives a better test than an incandescent lamp, as the latter will only indicate low-resistance grounds whereas the former will also indicate high-resistance grounds such as a slight defect in the insu-

lation allowing a little current to leak to the ground. Since a high-resistance ground will sooner or later develop into a low-resistance ground, its prompt correction is very desirable.

An open circuit in the field winding will cause a very low terminal voltage. Since there is no field the only possible generator terminal voltage will be that due to the residual magnetism in the poles. This will be very low, and the battery will pump back current through the generator tending to run it as a motor.

In the test of an open circuit in the field the apparatus is connected as shown in Fig. 487. If there is an open-circuit, the ammeter will show no deflection. In some cases the open may be located by inspection. If found to be of such a nature that it can be repaired by soldering, the coils will not have to be replaced by new ones. If the open circuit cannot be located, a new set of coils must be installed. On large machines, where each coil can easily be removed separately, the particular coil containing the open-circuit can be located by using a voltmeter with

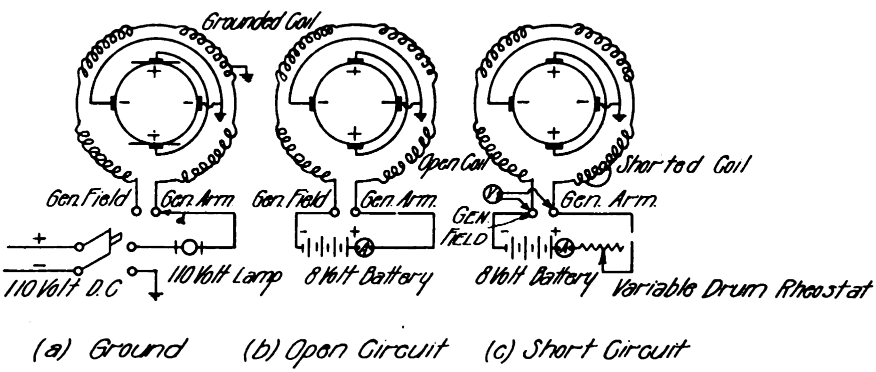

FIG. 487.—Connections for locating field circuit troubles.

a voltage range equal to the full potential of the source of power used in the test. With connections as shown in Fig. 487, the voltmeter is connected across the terminals of each coil separately. No deflection will result until the voltmeter is connected across the open coil in which case the voltmeter deflection will show full line potential.

A short-circuit in the field winding will cause low generator terminal voltage, excessive field current and overheating of that portion of the field winding not included in the short-circuit. The latter part of the field winding may ultimately burn out.

For locating a short-circuit in the field windings, connections are made as shown in Fig. 487 (*c*). The current, as read by the ammeter, is first adjusted to 1.75 amp. or normal field current. Then the voltage between *GEN. ARM* and *GEN. FIELD* terminals is read. This should be approximately 6.67 volts as shown in the log, Fig. 176, for the normal

coils. If there is a short-circuit, the voltmeter reading will be lower than 6.67 volts, the reading depending upon the nature of the short-circuit. If the short-circuit can be located and repaired by reinsulating, this is done. On the Liberty generator it will usually be found necessary to replace the coils with an entire new set.

264. Location of Open Armature Coils. In this test a special armature test fixture is used. This fixture may be used for practically all armatures met with in ignition practice. It can take armatures up to 8 in. in diameter and 12 in. shaft length. One of the shaft supports is adjustable and is furnished with a lock nut to hold the adjustment. The brush-holder device is also adjustable and is furnished with springs to give the necessary brush tension. No matter what the size of the commutator is, the brush rack will always hold the brushes 90 degrees apart on the commutator. Four binding posts and two single-pole switches make it possible to test for grounds, open coils and short-circuited coils without changing any other connections excepting the S.P.S.T. switches and connections to the source of power. This fixture with a Liberty armature in position is shown in Fig. 488. The connections between the board terminals are as shown in Fig. 179.

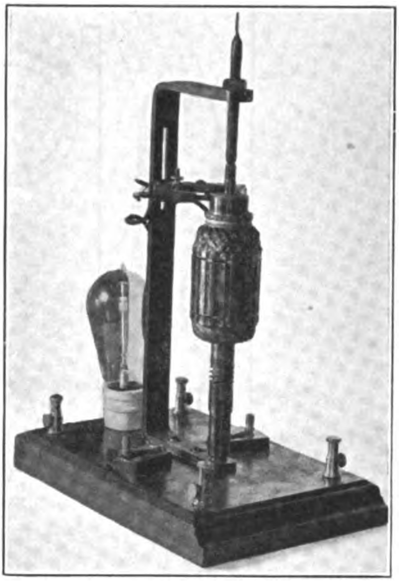

Fig. 488.—Armature test fixture.

An open armature coil tends to lower the terminal voltage causing excessive sparking, and several of the commutator bars may become somewhat blackened. These bars are connected to the armature coil containing the open-circuit.

In testing for an open armature coil the armature is placed in the fixture, as shown in Fig. 488 and the brushes are adjusted on the commutator. Then the variable drum rheostat, one ammeter and the 8-volt battery are connected in series between the binding posts marked No. 3 and No. 4 in Fig. 489. If the left-hand single pole, single throw switch is now closed, current will flow through the armature. This current as read on the ammeter is to be adjusted by means of the variable rheostat to between 7 and 10 amp. The test points, connected to the 0–15-volt terminals of a multiscale voltmeter, are placed on adjacent commutator bars and the voltmeter reading noted and recorded. The test points are now both moved over one bar on the commutator and the

voltmeter reading again recorded. This is continued until the voltage reading between each pair of adjacent bars has been determined. Throughout this test the test points can be kept in the same position and the armature rotated. The circuit diagram for this test is as shown in Fig. 489.

It will be found that the readings recorded during the test will be of three general magnitudes. There will be two very high readings at points 180 degrees apart on the commutator, quite a few zero readings and a

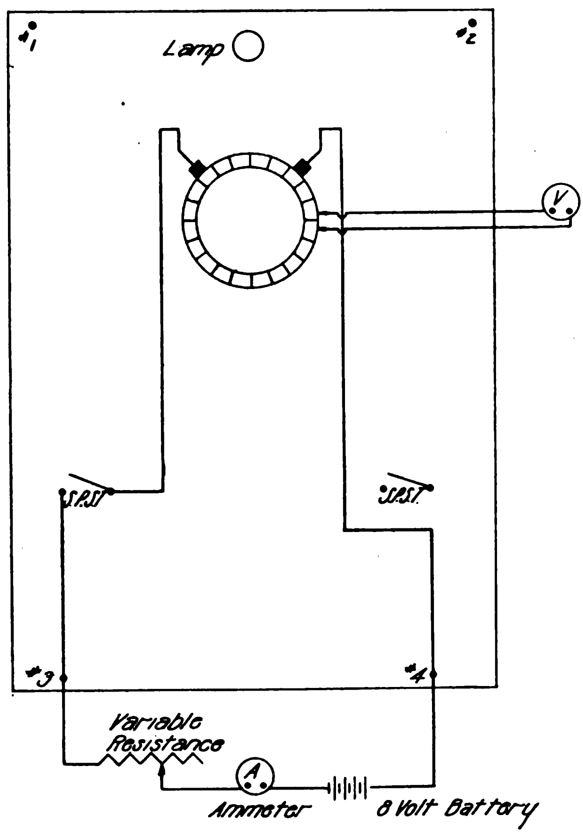

FIG. 489.—Circuit diagram for location of open armature coil.

a number of readings whose value will be somewhere between the high readings and zero. A typical set of readings is given in the log, Fig. 491. The two high readings between bars 6–7 and 16–17 show that the open coil lies between these bars. The zero readings are due to the fact that the coils soldered to these bars are connected in series with the open coil and, therefore, carry no current and have no voltage drop. The medium readings represent the normal voltage drop across the good coils carrying current.

The high reading of 4.5 volts between bars 6 and 7 is due to the fact that 6 is directly connected to the right-hand side of the open coil and 7 is connected to the left-hand side of the open coil through another coil on the lower side of the armature. In the same way, a high reading

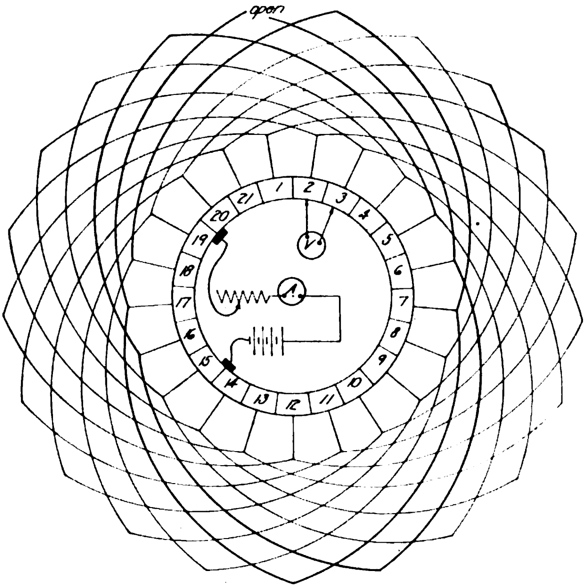

FIG. 490.—Circuit diagram of Liberty generator armature with an open coil.

occurs between bars 16 and 17 since the Liberty armature is wave wound and the ends of a wave-wound armature coil are attached to bars practically 180 electrical degrees apart. The reason for the high readings at these bars is the fact that since no current flows in the coils there is no

Bars	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	
Voltage Reading	9	8	0	0	0	4.5	0	0	.8	1.0	
Bars	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-1
Voltage Reading	9	9	9	0	0	4.7	0	0	0	.8	.9

FIG. 491.—Typical log for open armature coil test.

voltage drop around the commutator from the brushes up to these bars. This can be more easily understood by referring to Fig. 492.

Since no current flows in the left-hand half of the armature, there is no voltage drop in the coils in this half of the armature. Thus the bars

to which the ends of the open coil are connected are at the same potential as the two brushes. In the case of the wave-wound armature, two high readings are obtained for the reasons stated above. The zero readings occur across all the other bars on this side of the armature because there is no current and hence no voltage drop in these coils. The same holds for the wave-wound armature under test. The normal voltage drop will occur across all coils carrying current, these coils forming an unbroken circuit around the armature. In the lap-wound armature these normal readings will only occur in the right-hand half of the armature.

As previously stated an open armature coil tends to lower the terminal voltage of the generator, cause violent sparking at the brushes and burned commutator bars. To avoid excessive burning of the brushes and the

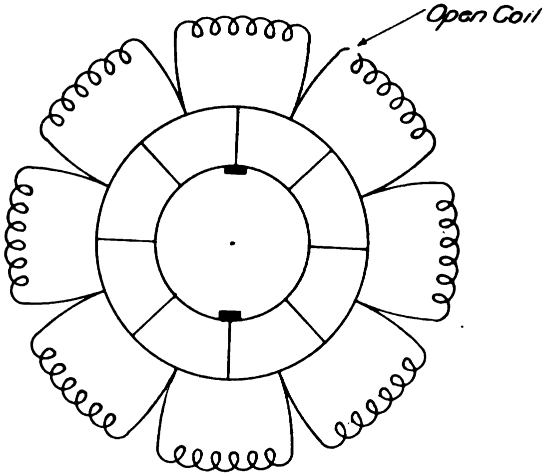

FIG. 492.—Diagram of a lap-wound armature with an open coil.

commutator, the trouble should be removed as soon as possible. In the Liberty generator, for the sake of greater reliability, the defective armature is replaced with a new one. The defective armature can then be repaired by rewinding the armature. On machines where absolute reliability is not as essential as in the case of the Liberty ignition system, the following temporary repair is often employed. The bars across which the open coil is connected are bridged temporarily by means of a copper wire or strip, preferably the latter, as shown in Fig. 493. The commutator bars are tapped and threaded and the copper bar is screwed up tight as shown in the illustration. In the case of a wave-wound machine, bridging two of the bars giving the high reading will eliminate the open coil, as indicated in two places on the commutator. The machine is then tested to determine whether all sparking has disappeared. It should be borne in mind that this is only a temporary remedy and the open coil should always be repaired or replaced with a new one as soon

as possible. Replacing a coil usually requires the work of a skilled armature winder and should never be attempted by anyone else.

265. Location of Short-circuited Armature Coils. The apparatus and the procedure used in this test are the same as in the preceding test. The only difference will be in the results obtained.

A short-circuited armature coil will cause overheating of a portion of the armature and lower terminal voltage. The overheating can usually

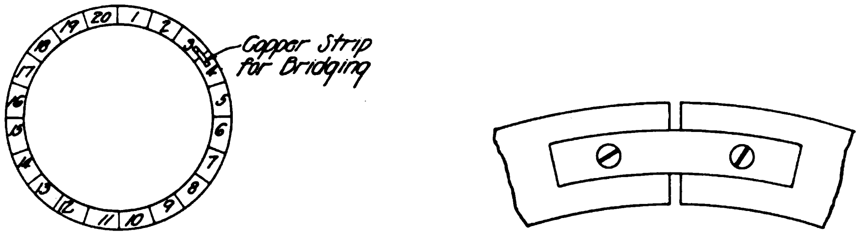

FIG. 493.—Temporary repair for open-circuited armature coil.

be detected by passing the hand over the armature immediately after the machine has been stopped.

If the machine is run for any length of time, this overheating will cause the coil to burn out, resulting in an open coil. It will also result in baked out insulation and grounds.

A typical set of readings obtained in the bar to bar test are given in the log, Fig. 494. The short-circuit was between bars 6 and 7 and a zero reading was obtained since there was no resistance and hence no voltage

COMMUTATOR BARS	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
VOLTAGE READING	.8	8	8	9	.8	0	.8	.8	.9	8	.8
COMMUTATOR BARS	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-1	
VOLTAGE READING	8	8	.85	.8	.8	.4	.45	.8	.8	.8	

FIG. 494.—Typical log for short-circuited armature coil test.

drop between the bars. Half way around the commutator or at the other ends of the short-circuited coil two low readings, about half normal value, were obtained. If only part of the coil has been short-circuited, the reading between bars 6 and 7 might have been 0.6 volts and between 17 and 18, and 18 and 19, about 0.7 volts. Thus it is seen that the actual magnitude of these readings will vary somewhat depending upon the position of the short-circuit in the coil. The readings must be made as carefully as possible as sometimes the variation is almost imperceptible.

Fig. 495 shows the Liberty generator armature with a complete short-circuit between bars 6 and 7.

As previously stated a short-circuited armature coil causes low terminal voltage and overheating of the short-circuited coil. The latter condition is very serious and must be remedied at once. In order to do this, the defective armature may be replaced; or it may sometimes be repaired by removing the short-circuit. The short-circuit will often be found to exist at or near the commutator riser, in which case it can usually be removed. If it is found necessary to substitute an entirely new armature the defective one can be repaired by rewinding.

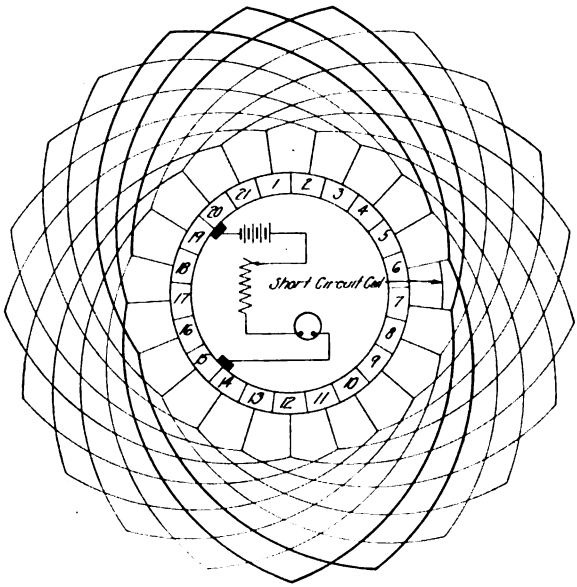

Fig. 495.—Circuit diagram of Liberty generator armature with a short-circuited coil.

266. Location of Grounded Armature Coil. *General tests for grounds in armature.* Since the negative armature terminal is grounded to the frame of the Liberty generator, a ground anywhere else in the armature will result in a short-circuit. The portion of the winding contained in this short-circuit depends upon the armature. This will result in a fluctuating terminal voltage and overheating of the entire armature winding.

In order to determine whether there is a ground anywhere in the armature it is first placed in the test fixture as shown in *a*, Fig. 496. The connections are as shown by the solid lines. The 110–125 volt direct current power is connected to binding posts No. 1 and No. 2. If there is a ground anywhere in the armature, the incandescent lamp will burn

as soon as the right-hand single pole, single throw switch is closed, because the circuit will be completed from the brush, through the ground in the armature, to the iron upright. This shows whether or not there is a ground anywhere in the armature circuit but does not locate the ground in any particular coil. In order to do this a separate test is made.

Location of grounded armature coil by bar to bar test. After an armature has been found to contain a ground, the particular coil in which this ground is situated is found in the following manner. The armature is placed in the test fixture and the 8-volt battery, variable, resistance, and the ammeter are connected in series between binding posts No. 3 and No. 4 as shown in the solid line, *b*, Fig. 496.

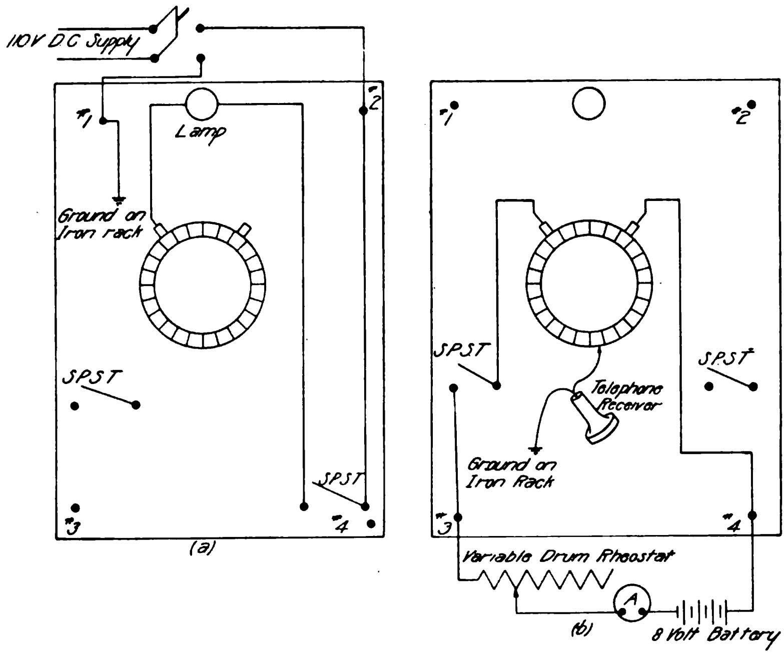

Fig. 496.—Circuit diagram for detection and location of grounded armature coils.

The left-hand S.P.S.T. switch is now closed and the current adjusted to between 7 and 10 amp. As additional apparatus, a telephone receiver fitted with a pair of test leads is required for this test. One lead terminal is grounded to the iron upright of the fixture under one of the holding nuts. The other test-lead terminal is then touched to one commutator bar after another. Each bar giving little or no sound is marked with chalk, the armature being stationary during the test. Fig. 497 shows the Liberty generator with a grounded armature coil.

As a rule, four bars will be found to give little or no sound in spite of the fact that there is only one grounded coil. Two of these bars are

connected to the grounded coil and the other two bars give no sound due to their position with respect to the grounded coil and the brushes. The latter are called phantom grounds. In order to determine which is the actual and which the phantom ground, the armature is revolved slightly, moving the brushes over one or two commutator bars. The test is now repeated and each bar giving little or no sound is marked as before. Since the phantom ground depends upon the relative position of the real

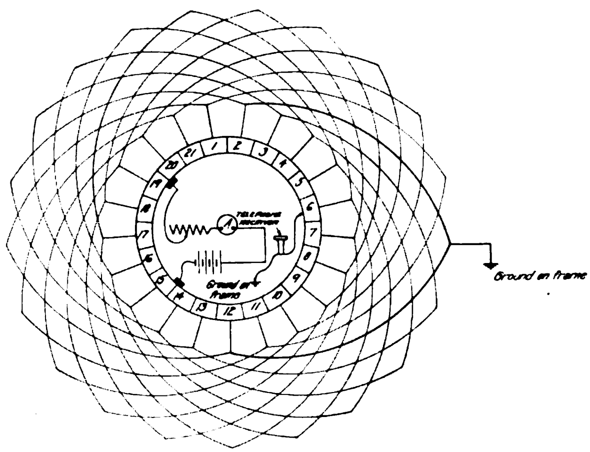

FIG. 497.—Circuit diagram of Liberty generator armature with grounded coil.

ground and the brushes its position will have shifted to other bars whereas the real ground will still be on the same bars as before the armature was rotated. A typical log of results is shown in Fig. 498.

As seen from the results given in Fig. 498, and by reference to Fig. 497, the real ground is situated between bars 2 and 12. Therefore both of these bars will give little or no sound regardless of their position with

	BARS GIVING LITTLE OR NO SOUND
First Arm. Position	#2, #12, #18, #8
Second Arm. Position	#2, #12, #15, #5

FIG. 498.—Typical log for locating a grounded armature coil.

respect to the brushes. In the first setting, bars 18 and 8 give practically no sound, due to their position with respect to the brushes. Since the armature position was changed before the second test was made they no longer gave a sound, but bars 15 and 5 were the ones whose position with respect to the brushes caused them to give no sound.

Bars 18 and 8, in the first test, and 15 and 5 in the second test, are

said to give phantom ground readings. In order to understand what causes a phantom ground, it is necessary to refer to the action of the telephone receiver. It will give a click whenever there is a voltage difference between the test points. When the storage battery is connected as shown in *b*, Fig. 496 the potential of the iron upright is the same as the potential in some part of the battery. Somewhere in that part of the armature winding, which is not in series with the grounded portion, there will be a potential the same as the potential of the iron upright. This is due to the fact that, starting from the positive battery terminal and passing through the circuit not containing the grounded coil, there is a continuous voltage drop. Somewhere between the two brushes there must, therefore, be a potential the same as the potential of the iron upright with respect to the positive brush. If this bar is touched with the ungrounded test lead no sound will result. A similar no-sound point will be situated half-way around the commutator from this bar, since the two points are interconnected by means of a coil. This can be more

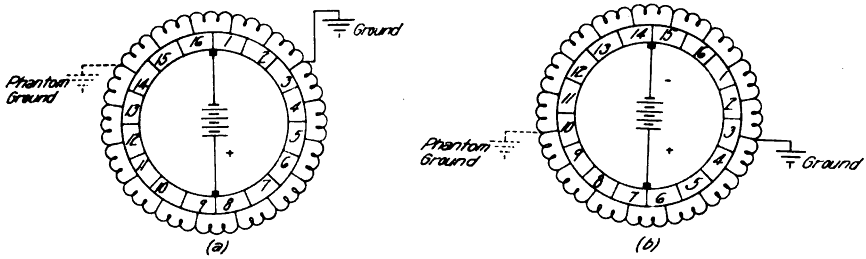

Fig. 499.—Lap-wound armature with a grounded coil.

easily understood by reference to the lap-wound armature shown in Fig. 499.

In a lap-wound machine there are only two readings, one real and one phantom ground, since the coil terminals are attached to adjacent bars instead of bars practically 180 electrical degrees apart as in a wave-wound armature.

Referring to Fig. 499, it can be seen that the real ground is in the coil the ends of which are soldered to bars 2 and 3. The ground is nearer bar 3 and this bar will give no sound in positions *a* and *b*. Again, there are eight commutator bars in each half of the armature between brushes. Now in *a*, bar 3 is the third bar to the right from the negative battery terminal. At the third bar to the left there will be a phantom ground reading, namely at bar 14, since this bar is at the same potential with respect to the negative battery terminal, as 3 with the real ground.

When the armature is shifted to position *b*, the real ground is still at bar 3, which gives no sound. This is now the fifth bar around to the left from the negative battery terminal; the fifth bar around to the left

from the negative battery terminal is bar 10, hence this bar gives no sound.

The results are the same with a wave-wound armature except that twice the number of readings are obtained, due to the reason previously stated. In addition, the armature circuits are made more complex and difficult to explain. Since the object of the test is to locate the real ground and eliminate the effect of the phantom, it is sufficient to know why there is a phantom and how to distinguish it from the real ground.

It is very important not to use an armature containing a grounded coil in the Liberty system, as the negative battery terminal is grounded and one ground in the armature will result in a short-circuit, with consequent overheating of the armature and possible burning out of the coils. For this reason, unless the ground is found by inspection to be at some point where the insulation can be easily repaired and the ground thereby entirely removed, a new armature is always substituted for the defective one. An experienced armature winder can then remove the grounded coil and either reinsulate it or substitute a new coil.

Magneto Operating Troubles and Maintenance. Wound and Non-wound Armature Aircraft Engine Types.

267. Operating Troubles. *Improper adjustment of interrupter points.* The result of too small a breaker-gap opening will be as follows: At low speed there will be abnormal sparking at the breaker points, and the secondary spark will be weak and irregular. At high speed, no abnormal sparking at the breaker points will be detected, as the increased speed will break the primary circuit more rapidly. The secondary spark will be normal.

If the interrupter-gap opening is too large, the following effects will be noticed. At low speed there will be no abnormal sparking at the breaker points and the secondary spark will be normal. At high speed the sparking at the breaker points will be abnormal, and the wear on the platinum points will be quite noticeable, due to the pounding action. The secondary spark will be weak and irregular.

Improper distributor gear setting. If distributor gear is three or four teeth behind the distributor gear driving pinion, in time it will cause the following effects: With the spark lever in retard position and with the magneto driven at low speed, no change in the secondary spark will be noticed and the magneto will function properly.

With the spark lever in the advance position, the following effects will be noticed. The distributor brush will be in a position back of the proper distributor segment when the interrupter points open. As the spark will have to jump to that segment from the distributor brush, it will have a burning action on the segment and on the rotor track between

the brush and segment. This roughness will cause the brush to wear and smear the rotor track with carbon, causing an irregular secondary spark. The spark will possibly jump the safety gap at times, depending upon the distance between the distributor brush and the distributor segment.

At high speed, with the spark lever in retard position, the following effects will be noticed. If the rotor track has not been roughened and smeared, no ill effects will be noticed. If the track has been roughened, as noted above, the secondary spark will be irregular.

With the spark lever in the advance position the following effects will be noticed. The burning action on the distributor segment and rotor track will be more pronounced, due to the better spark which is obtained at the higher speed. The secondary spark will be irregular. If the distributor-gear setting is six or seven teeth behind that of distributor-gear driving pinion it will cause the following effects. With the spark lever in retard position and the magneto driven at low speed, the spark may have a small space to jump to the segment and rotor track. Probably no difference in the secondary spark will be noticed. Without the spark lever in the advance position the effects will be somewhat different. The spark may jump to the proper distributor segment, to the one behind it, or it may jump the safety gap; it will be noted that some terminals will receive two sparks while others get none. This will result in an uneven running engine. At high speed, the same conditions will exist. With the distributor-gear setting three or four teeth ahead of the pinion gear, the following effects will be noticed. With the spark lever in retard position, the distributor brush will have passed the segment when the interrupter points open, thus causing the spark to jump from the brush to the segment. This will cause a burning action on the segment and the rotor track. The spark may jump at the safety gap. The secondary spark at the plug gap may be irregular. With the spark lever in the advance position the distributor brush will make contact with the segment and the operation will be normal.

At high speed the same effects will be noticed.

With the distributor gear six or seven teeth ahead of drive pinion the following effects will be noticed: With the magneto driven at low speed and the spark lever in retard position, the spark may jump to the segment ahead of the distributor brush, to the one behind it, or the safety gap, resulting in one spark plug gap getting two sparks and the other none. In starting the engine it may kick back resulting in serious damage. If it can be started, it will run unevenly. With the spark lever in advance position the following effects may be noticed. The spark may jump to the proper segment, or it may jump the safety gap, and the burning effect will take place. The secondary spark at the spark plug gap will be irregular.

At high speed the same effects will be noticed.

Defective Insulation. Defective insulation, in primary windings or leads, may cause the following effects. At low speed, defective insulation will have no effect unless that lead or part of winding which is defective comes in contact with other parts causing a partial short-circuit or ground. In this case, the secondary spark will be weak or perhaps no spark will be obtained. At high speed the short-circuit or ground may become more pronounced, due to the higher centrifugal force. The resulting secondary spark will be weak or no spark will be obtained.

Defective insulation in secondary windings, leads, and high-tension connections will at low speed have the following effect. The secondary spark may jump to the nearest ground, causing the spark at the spark-plug gap to be irregular. If the insulation is broken to such an extent that the spark will have a direct route to the ground, no secondary spark will be obtained.

At high speed this effect will be more pronounced, due to the increased intensity of the spark.

268. Maintenance. Magnetos, both wound and non-wound armature types, which have been purposely made inoperative, are to be given initial inspection and test to locate troubles. Adjustments, replacements, and repairs are to be made where necessary. Final inspection and tests are given before the magneto is available for actual service.

Initial Inspection. Remove the interrupter box cover and examine interrupter mechanism for such things as dirty or pitted points, improper gap, worn rubbing block, loose primary lead, and sticking of any moving parts. Examine the grounding brush insulation in the interrupter box cap. Remove the distributor block and examine the insulation, the segments, the brush, and the rotor track for cleanliness. Inspect the high-tension pencil insulation and the collector brush.

Initial Test. The magneto must first be given a low speed test at 100 to 150 r.p.m. By means of adjustable secondary gaps, note if there is any abnormal sparking at the interrupter gap. Note also the length of the gap that the secondary spark will jump and see if any spark jump the safety gap instead of the adjustable gap.

The magneto should now be given a high-speed test at about 1,500 r.p.m. noting the same conditions as in the low speed test. The troubles are to be determined from these tests.

Adjustments, Replacements and Repairs. Adjustments, replacements and repairs are to be made where necessary to bring the magneto up to the highest possible point of efficiency.

The following chart shows various magneto troubles, effects on performance, engine operation, and remedies for these troubles.

TABLE XLV.—EFFECTS ON PERFORMANCE.

Troubles	Low speed	High speed	Remedies
Interrupter points pitted or dirty.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Clean points. Dress down points with platinum file.
Interrupter gap too large.	Normal operation.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Adjust to proper gap.
Interrupter gap too small.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Normal operation.	Adjust to proper gap.
Insulation between interrupter block and interrupter base short-circuited.	No secondary spark. Engine stops.	No secondary spark. Engine stops.	Replace with new spring.
Weak interrupter-arm spring.	Normal operation.	Interrupted points chatter. Weak secondary spark. Engine misses.	Replace with new spring.
Binding of movable interrupter-arm.	Irregular or no secondary spark. Engine misses or stops.	Irregular or no secondary spark. Engine misses or stops.	Replace arm, or ream bushing.
Interrupter spring broken.	Occasional or no secondary spark. Engine stops.	Occasional or no secondary spark. Engine stops.	Replace with new spring.
Broken rubbing block.	Interrupter points do not open. No secondary spark. Engine stops.	Interrupter points do not open. No secondary spark. Engine stops.	Replace with new rubbing block.
Worn cams.	Variation in time and amount of interrupter gap opening. Possible weak secondary spark. Engine may miss.	Variation in time and amount of interrupter gap opening. Possible weak secondary spark. Engine may miss.	Replace with new cams or make them identical.
Grounding brush. Insulation in interrupter cover short-circuited.	No secondary spark. Engine stops.	No secondary spark. Engine stops.	Replace with new insulation.
Ground wire grounded.	No secondary spark. Engine stops.	No secondary spark. Engine stops.	Replace with new wire.
Ground wire open-circuited.	Engine will not stop when ground switch is closed.	Engine will not stop when ground switch is closed.	Close open-circuit. Replace with new wire.
Interrupter mounting screw loose (wound-armature type magneto).	Poor primary connection. Weak or no secondary spark. Engine misses or stops.	Poor primary connection. Weak or no secondary spark. Engine misses or stops.	Tighten the interrupter mounting screw.
Primary lead in interrupter loose (Dixie magneto).	Poor primary connection. Weak or no secondary spark. Engine misses or stops.	Poor primary connection. Weak or no secondary spark. Engine misses or stops.	Tighten connection.
Primary lead in interrupter grounded (Dixie magneto).	Irregular or no secondary spark. Engine misses or stops.	Irregular or no secondary spark. Engine misses or stops.	Reinsulate or replace with new lead.
Interrupter recoil spring loose or missing.	Interrupter points may chatter. Possible weak secondary spark. Engine may miss.	Interrupter points chatter. Weak secondary spark. Engine misses.	Tighten or install new spring.

TABLE XLV.—EFFECTS ON PERFORMANCE (*Continued*)

Troubles	Low speed	High speed	Remedies
Interrupter base grounding brush dirty or spring tension poor.	Irregular secondary spark. Engine misses.	Irregular secondary spark. Engine misses.	Clean brush and track. Replace spring.
Camshaft housing worn or loose.	May have same effect as worn cams.	May have same effect as worn cams.	Replace with new housing.
Armature bearing worn.	May have same effect as worn cams.	Same effect, but more pronounced than at low speed.	Replace with new bearing.
Distributor gear out of time with armature.	Irregular or no secondary spark at plugs. Sparks may jump safety gap. Engine may cross-fire or will not start.	Irregular or no secondary spark at plugs. Sparks may jump safety gap. Engine may cross-fire or will not start.	Reset distributor gear with respect to armature.
Rotor wing gap too wide or too narrow. (Dixie magneto.)	Weak secondary spark. Engine may miss.	Weak secondary spark. Engine may miss.	Adjust to proper gap.
Distributor-block cover punctured or short-circuited.	Irregular or no secondary spark at plugs. Engine misses, cross-fires or stops.	Irregular or no secondary spark at plugs. Engine misses, cross-fires or stops.	Replace with new cover.
Distributor block punctured or short-circuited.	Irregular or no secondary spark at plugs. Engine misses, cross-fires or stops.	Irregular secondary spark at plugs. Engine misses, cross-fires or stops.	Replace with new block.
Distributor rotor track and segments worn.	Possible irregular secondary spark at plugs. Spark may jump safety gap. Engine may miss.	Irregular secondary spark at plugs. Spark may jump safety gap. Engine misses.	Replace with new block.
Distributor finger assembly punctured or short-circuited.	Irregular or no secondary spark at plugs. Engine misses or stops.	Irregular or no secondary spark at plugs. Engine misses or stops.	Replace with new parts.
Distributor-rotor brush broken, or missing.	Irregular or no secondary spark at plugs. Spark may jump safety gap. Engine misses or stops.	Irregular or no secondary spark at plugs. Spark may jump safety gap. Engine misses or stops.	Replace rotor brush.
Collector-brush assembly punctured or short-circuited.	Irregular or no secondary spark at plug. Engine misses or stops.	Irregular or no secondary spark at plug. Engine misses or stops.	Replace with new part.
Collector brush missing or weak spring tension.	Irregular or no secondary spark at plug. Spark may jump safety gap. Engine misses or stops.	Irregular or no secondary spark at plug. Spark may jump safety gap. Engine misses or stops.	Replace brush or spring.
High-tension pencil insulation punctured or short-circuited.	Irregular or no secondary spark at plugs. Engine misses or stops.	Irregular or no secondary spark at plugs. Engine misses or stops.	Replace with new pencil.
Condenser connection loose.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Tighten connection.
Condenser open-circuited.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Repair "open." Replace condenser.

TABLE XLV.—EFFECTS ON PERFORMANCE (*Continued*)

Troubles	Low speed	High speed	Remedies
Condenser short-circuited.	No secondary spark. Engine stops.	No secondary spark. Engine stops.	Remove short-circuit. Replace condenser.
Leaky condenser.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Abnormal sparking at interrupter points. Weak secondary spark. Engine misses.	Replace with new condenser.
Safety gap too small.	No secondary spark at plugs. Engine will not start.	No secondary spark at plugs. Engine will not start.	Adjust to proper gap.
Collector spool insulation punctured or short-circuited.	Irregular or no secondary spark. Engine misses, stops or will not start.	Irregular or no secondary spark. Engine misses or stops.	Replace with new spool.
High-tension lead punctured or short-circuited.	Irregular or no secondary spark. Engine misses, stops or will not start.	Irregular or no secondary spark. Engine misses or stops.	Reinsulate.
High-tension lead open-circuited.	Irregular or no secondary spark. Engine misses or stops.	Irregular or no secondary spark. Engine misses or stops.	Repair "open." Replace coil.
High-tension winding open-circuited.	Irregular or no secondary spark. Engine misses or stops.	Irregular or no secondary spark. Engine misses or stops.	Repair "open" or replace coil.
High-tension winding short-circuited or grounded.	No secondary spark. Engine stops.	No secondary spark. Engine stops.	Reinsulate or replace coil.
High-tension insulation punctured.	No secondary spark. Engine stops.	No secondary spark. Engine stops.	Reinsulate or replace.
Primary winding short-circuited.	Irregular or no secondary spark. Engine misses or stops.	Irregular or no secondary spark. Engine misses or stops.	Remove short-circuit or replace coil.
Primary winding open-circuited.	No secondary spark. Engine stops.	No secondary spark. Engine stops.	Repair "open" or replace coil.
Primary lead short-circuited or grounded.	Irregular or no secondary spark. Engine misses or stops.	Irregular or no secondary spark. Engine misses or stops.	Reinsulate or replace lead.
Primary leads open-circuited.	No secondary spark. Engine stops.	No secondary spark. Engine stops.	Repair "open" or replace lead.
Weak magnets.	Weak secondary spark. Engine misses.	Secondary spark may be weak. Engine may miss.	Recharge magnets.
Magnets reversed.	No secondary spark. Engine will not start.	No secondary spark. Engine will not start.	Install correcty.
Magnet broken.	Secondary spark may be weak. Engine may miss.	Secondary spark may be weak. Engine may miss.	Replace magnet.
Armature heads loose.	Possible irregular or weak secondary spark. Engine may miss. Mechanical interference.	Possible irregular or weak secondary spark. Engine may miss. Mechanical interference.	Tighten and stakel screws.
Armature shaft out of line.	Possible irregular or weak secondary spark. Engine may miss. Mechanical interference.	Possible irregular or weak secondary spark. Engine may miss. Mechanical interference.	Replace shaft.
Distributor gear teeth broken.	Secondary spark irregular at plugs. Spark may jump safety gap. Engine may crossfire or stop.	Secondary spark irregular at plugs. Spark may jump safety gap. Engine may crossfire or stop.	Replace gear.

TABLE XLV.—EFFECTS ON PERFORMANCE (*Continued*)

Troubles	Low speed	High speed	Remedies
Distributor pinion gear teeth broken.	Secondary spark irregular at plugs. Spark may jump safety gap. Engine may crossfire or stop.	Secondary spark irregular at plugs. Spark may jump safety gap. Engine may crossfire or stop.	Replace gear.
Armature bearing broken.	Secondary spark irregular and weak. Magneto noisy and vibrates. Engine misses or stops.	Secondary spark irregular and weak. Magneto noisy and vibrates. Engine misses or stops.	Replace bearing.
Distributor gear bearing broken.	Secondary spark irregular at plugs. Spark may jump safety gap. Engine may crossfire or stop.	Secondary spark irregular at plugs. Spark may jump safety gap. Engine may crossfire or stop.	Replace bearing.

Final Inspection and Test. The magneto should be installed on a test stand and provided with a positive drive. It should be connected to as many adjustable spark gaps as there are terminals on the distributor block. The gaps have a clearance of 5 mm. or .197 in. Drive the magneto at low speed, 100 to 150 r.p.m. It should generate a spark for two consecutive minutes without missing.

Drive magneto at high speed, about 1500 r.p.m., using the same gap, for thirty minutes. There should be no abnormal sparking at the interrupter points nor missing of secondary sparks. The magneto can now be put into service.

Liberty Ignition System Operating Troubles and Maintenance.

269. Low-tension Wiring. *Use of Test Points.* In many tests, such as those for the location of open-circuits, grounds, short-circuits and in tests for determining the insulation resistance of various pieces of insulated apparatus, it will be found that a set of test points can be used to great advantage. For this reason it is advisable to construct one or more of these sets of points so as to have them always available. A convenient type is shown in Fig. 500. The approximate dimensions are given in Fig. 500. The test leads are soldered into one end of the brass lug and the other end is drilled to take test needles of various sizes. A set screw fitting into a tapped hole, serves to hold the needle rigidly in place. By using a sharp needle it is possible to make connection with the wire of an insulated winding by punching right through the insulation.

The first test will be to locate grounds in the low-tension wiring of the Liberty ignition system. The connections for this test are shown in Fig. 501. First remove all normal grounds, that is, the generator, low-tension coil, and battery grounds. The first may be quickly done by

inserting cardboard strips under the two positive brushes. After this has been done one side of the power line is grounded on the frame of the generator. If the power line is connected to a grounded supply system, the grounded side of the line should be grounded on the generator frame so as not to short-circuit the system. If the ungrounded line were grounded on the frame, any connection between the grounded line and

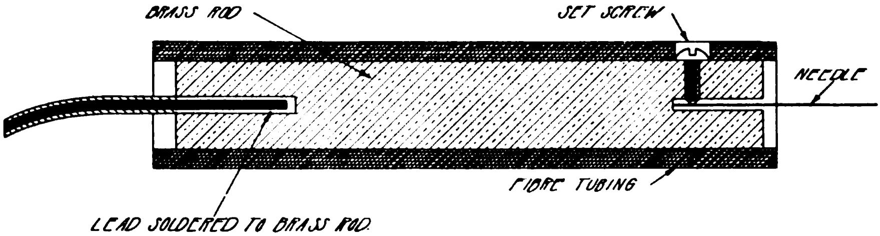

FIG. 500.—Test point.

the frame would cause the supply line to be short-circuited. With connections made as shown in Fig. 501 the ungrounded test point is placed in contact with the frame to test the lamp, which should burn under these conditions. If the lamp does not burn a new one should be substituted and the test repeated. This serves as a test for the condition of the lamp and also shows whether there is a good ground connection on the

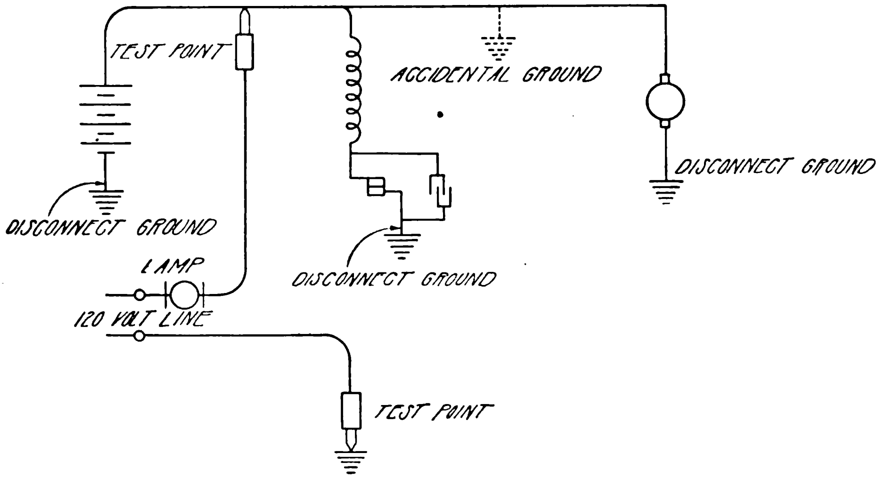

FIG. 501.—Diagram of connections for testing for grounds in primary circuit.

grounded test point. The ungrounded test point is now placed in contact with the low-tension wiring. If the lamp burns it shows that there is a ground somewhere in this wiring. By testing each part, when disconnected from the remainder, the portion containing the ground may be located by a process of elimination. The final location must always

be done by inspection. To remove the ground the wire may be reinsulated with rubber tape or a new piece of wire substituted, the latter being preferable.

In detecting and locating open-circuits all normal grounds are first removed as in the previous test. Then the test points, neither one grounded, are touched to the ends of the wiring circuit. Any opening in the wiring would prevent the lamp from burning. By holding one test point at one end of the circuit and moving the other one along the wiring the exact location of the "open" can be determined by a process of elimination. The opening may merely be a loose connection, in which case it can be removed by tightening the holding nuts. If the wire is broken it might be soldered together, but is better, for the sake of reliability, to substitute a new piece of wire.

Short-circuits must be located by inspection, as the entire low-tension wiring has such a low resistance that a comparative resistance test would not be accurate enough to detect the short-circuit. Short-circuits may usually be removed by reinsulating the wires but the best practice is to substitute new wire.

270. Coils. The most common troubles experienced with ignition coils are due to an open-circuit or a short-circuit in the primary or secondary windings.

In the case of an open-circuited primary winding, the symptom in operation is no secondary spark, since no current will flow in the primary. This only applies when the primary is totally open. If the open-circuit is of such a nature that the ends of the break just make contact, the secondary spark will be intermittent or weak, depending on whether vibration has any effect or not. This latter case can only exist near the terminals, as the rest of the winding is so wound that it gives either a permanent open or none at all. If the primary winding is short-circuited, the secondary voltage is reduced; the greater the percentage of turns shorted, the larger the reduction of the secondary voltage. It must be remembered that the resistance of the primary decreases as the number of turns shorted increases. This will cause excessive current to flow through the primary winding, which results in violent sparking at the breaker points. If an ammeter were placed in the primary circuit, as is the case in a generator-battery system, the reading on the meter would give a good indication of what is taking place. In some cases, where a considerable number of turns are shorted, the low-tension leads will heat up due to the excessive current flowing. If a few turns are short-circuited, the operation is still normal, due to the current increasing. This current, however, will overheat the remainder of the winding and result in shorting more turns and finally burning out the coil.

Defects in the secondary winding will give slightly different results. If the secondary is open-circuited, the spark will jump the break, provided

it is not too large. This will give a good spark across the secondary gap. In time, the arcing across the break will burn out the insulation of the adjacent layers. This will result in causing the adjacent layers to become inoperative, in other words reducing the number of turns of the secondary. Since the ratio of transformation is reduced, the secondary voltage is lower. The effect is accumulative and therefore, in time, the whole winding will be burned out. If the secondary is short-circuited, the secondary voltage is directly decreased, since the ratio of transformation is decreased. Under the latter condition, if the engine is accelerated under load, it will misfire. This is due to the fact that the compression in the cylinder is increased, and therefore a higher secondary voltage is required to jump the spark-plug gap, which is now of higher resistance.

When a coil is suspected of being defective, a convenient preliminary test to verify this is by comparison with a good coil. The setup for this

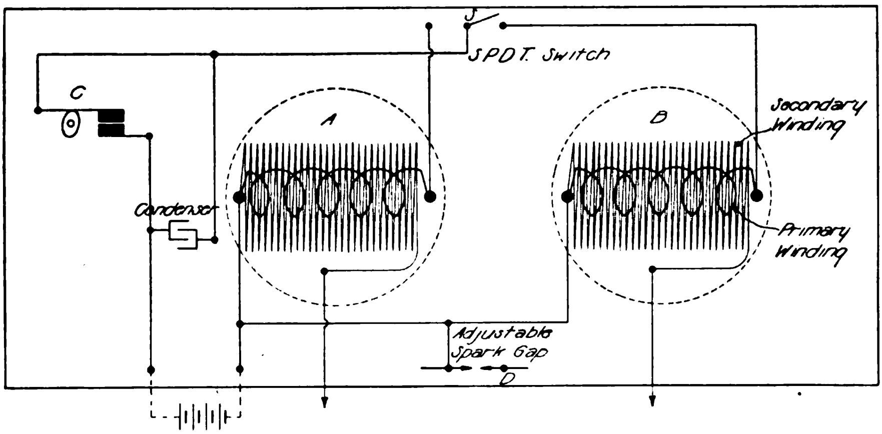

Fig. 502.—Test of an ignition coil by comparison method.

test is shown in Fig. 502. *A* is a good coil of the same type as the coil *B* to be tested. *C* is any convenient breaker mechanism. With the switch *S* thrown to the left, and the secondary lead of coil *A* connected to *D*, the secondary gap may be adjusted to determine the maximum spark that the good coil will give. If the switch is then thrown to the right and the secondary lead of coil *B* connected to *D*, the maximum secondary spark that can be obtained from coil *B* is measured by the adjustable gap and will indicate whether or not it is in proper condition.

After it has been determined by the foregoing test, that there is coil trouble, in order to exactly locate the trouble, the primary should be tested by the following method, the setup for which is shown in Fig. 503. A current is passed through the primary, and the voltage drop across

the primary is measured. The resistance R can be calculated by Ohm's Law.

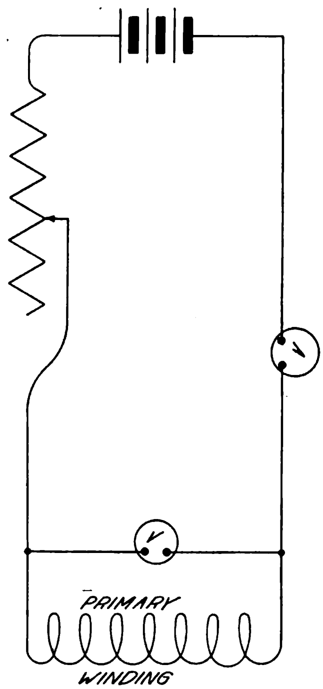

FIG. 503.—Test of primary winding by voltmeter ammeter method.

$$R = \frac{E}{I} \text{ where } E = \text{voltage drop across primary.}$$
$$\text{where } I = \text{current through primary.}$$

The same test should be made on a good coil. If the resistance of the defective coil is lower than the good coil, it indicates a short-circuit in the winding. If the resistance is higher, it shows a poor connection somewhere in the winding. An open-circuited winding will permit no current to flow and will show no reading on the ammeter, that is, the resistance is infinite.

If no trouble is found in the primary, the secondary should then be tested by the method shown in Fig. 504. The secondary of the defective coil is connected in series with a voltmeter, 150-volt range, to a 120-volt direct-current line. The power line need not be exactly 120 volts, but approximately. If manufacturer's data is not always available, it is necessary to test the secondaries of a number of good coils and the average of these voltmeter readings taken as a standard. If the defective coil shows a higher reading than

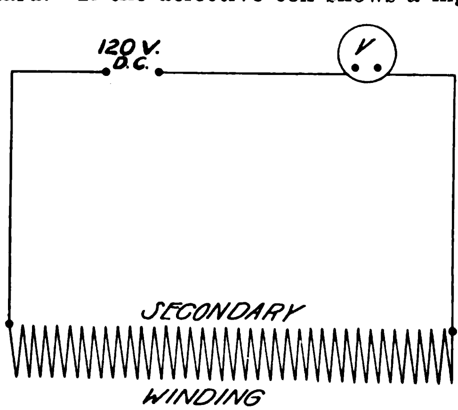

FIG. 504.—Test of secondary winding by voltmeter method.

the standard value, the coil is short-circuited. The higher the reading, the greater the number of turns short-circuited, since more current

flows. If the secondary is open-circuited, very little current can flow through the winding and therefore through the meter. This small current is due to the fact that the arcing across the open will burn the insulation and thereby form a carbon path. A small amount of current leaking between layers will also flow through the meter, but both will only cause a very small deflection. In addition to the above, if the line voltage is read and the resistance of the voltmeter known, the resistance of the secondary winding may be calculated from the following formula:

$$R = \frac{R_v (E - e)}{e}$$

where R = resistance of secondary to be measured.
R_v = resistance of voltmeter.
E = voltage of power source as measured by the voltmeter.
e = reading on voltmeter when winding is in circuit.

It follows from the above formula that if the reading e is high, R will be low. The reading e increases with the current, in other words, as the resistance of the total circuit decreases.

271. Condensers. The troubles met with in condensers may be classified, as short-circuited, leaky and open-circuited condensers. When the insulation between the plates of a condenser breaks down, current will then flow from one set of plates to the other, that is, through the condenser. With a condenser in this condition, an ignition system will not function at all, because the primary current will be permanently grounded through the condenser, and will not be interrupted by the opening of the breaker points. A leaky condenser is one in which the insulation has deteriorated, due to heat, atmospheric conditions or other causes, so that while not totally short-circuited, it will permit some current to leak from one side to the other. The effect of a leaky condenser will be to reduce the intensity of the spark at the plug. In this case, the condenser will bulge out, and in practice it is known as a bulged condenser. A condenser is open-circuited when one of the leads is disconnected from the plates. An ignition system with an open-circuited condenser will act in the same manner as if the condenser had been removed, namely, there will be abnormal sparking at the breaker points and a weaker spark at the plug.

To test a condenser that is suspected of being defective, one of two methods may be used, depending upon whether alternating or direct-current is available. Fig. 195 shows the connections for both methods. With the direct current method, the condenser is charged when the swtich is closed and the points P separated. When the switch is opened and the points P are brought together the condenser is discharged. If the condenser under test is in good condition, the lamp will not light when the switch is closed, and a good spark will be obtained at the points P when

they are brought together. If the condenser is open-circuited, the lamp will not light when the switch is closed, and no spark will be obtained at the points P when they are brought together. The latter is due to the fact that the condenser receives no charge, since it is open-circuited. If the condenser is short-circuited, the lamp will light when the switch is closed, since the circuit is complete through the condenser.

If an alternating voltage is impressed across a condenser, an alternating current flows in the circuit, the strength of the current depending upon the voltage impressed and the capacity of the condenser. Since the capacity of the condensers used in ignition is low, only a small current will flow, which is not sufficient to light the lamp. If the condenser under test is in good condition, the lamp will not light on closing the switch, but when the switch is opened a small spark is produced at the switch, due to the current flowing. If the condenser is open-circuited, the lamp will not light and no spark will be obtained when the switch is opened. If the condenser is short-circuited, the lamp will light upon

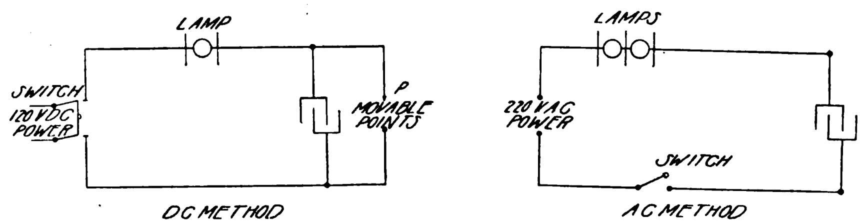

FIG. 505.—Connections for testing condenser.

closing the switch and a larger spark will be obtained when the switch is opened.

The reliability of the above tests increases with the voltage impressed across the condenser. It must be borne in mind that too high a voltage will break down the insulation and thus ruin the condenser. For paraffin paper condensers, voltages up to 240 volts may be used, while mica condensers will stand 500 volts. In either case, one lamp for approximately each 120 volts is placed in series, so as to limit the flow of current if the condenser were short-circuited or badly leaky.

The above methods are more or less of a qualitative nature, so much so, that if the condenser were slightly defective it would probably give an affirmative test. A far better test is to operate the ignition system, first with the condenser which is believed to be defective, and then with a condenser of the same rated capacity, known to be in good condition. A comparison of the operation of the system under the two conditions will indicate whether the first condenser is defective or good. This latter test is very reliable and is often used in practice, especially for condensers thought to be leaky.

272. High-tension Insulation. In practice it is sometimes necessary to test the distribution system for leaks. This is easily accomplished by subjecting the insulation to a pulsating voltage of about 12,000 volts, which is obtained from a vibrating coil. The secondary is set at ½ in. which allows the voltage to rise only to about 12,000 volts. If a crack

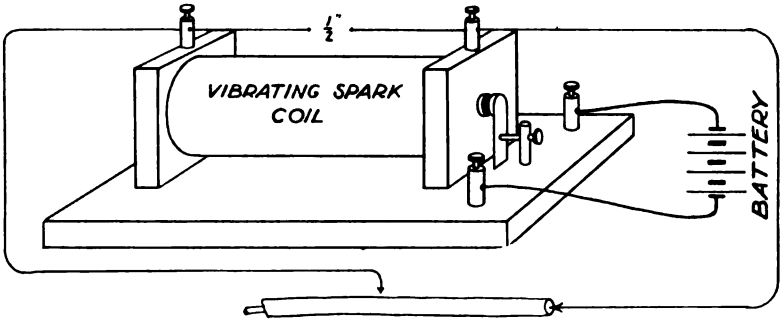

FIG. 506.—High-tension insulation test.

or cut exists in the insulation a shower of sparks will be noted as the secondary wire is passed over the poor portion of the lead. In some cases where the cable has become soaked, a great many violet blue paths will be seen around and along the cable and the spark no longer jumps the gap of the vibrating coil. When the cable or any other accessory which

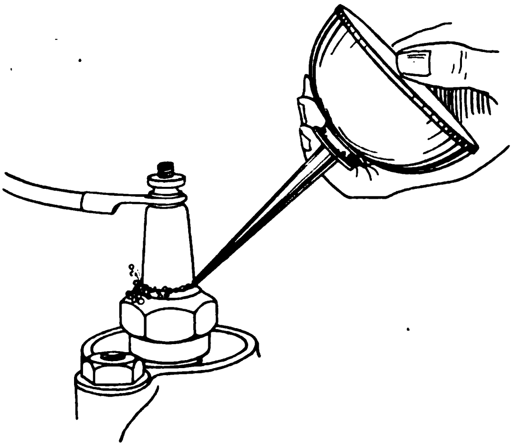

FIG. 507.—Method of testing for leaks in spark plugs.

is to be tested, is totally enclosed, breakdown takes place when the spark no longer jumps the vibrating coil gap.

273. Spark Plugs. The defects which may exist in spark plugs are leaky joints, poor or leaky insulation, and improper adjustment of the gap. The tests necessary to determine these defects are very different.

A spark plug having a leaky joint is placed in a compression chamber or cylinder of an engine and subjected to a pressure of 80 to 120 lbs. per sq. in., depending upon the engine on which it is to be used. Gasoline is then squirted at points *H* and *B*, Fig. 507. If bubbles appear at these joints the plug is leaky.

The insulator may conduct the secondary spark away from the electrode points due to the following conditions: the insulator may be cracked, or enough soot has accumulated to short-circuit the plug. The best way to test for this trouble is to take the plug apart, if it is the demountable type, and test the insulator as in the case of high-tension leads. If the plug is not demountable it is necessary to place it in a compression chamber and test it at the pressure at which it is used. Under these conditions the spark will not occur at the points because of the higher resistance due to higher pressure, but across the leaky portion. The same plug in air may give a very good spark across the points.

The same symptoms, that is a good spark in air, but no spark under compression, will result in the case of a spark plug having too wide a gap. Therefore the gap should be accurately adjusted. This should be done by moving the grounded electrode rather than the central one because of the danger of cracking the insulator.

CHAPTER IX

AIRCRAFT ENGINE LABORATORY

Preliminary Lecture

274. Purpose and Scope of Work. The purpose of the aircraft engine laboratory is to apply theory to practical methods and at the same time eliminate from the student's mind many of the ideas which are based on automobile engine practice. In aircraft engine practice the methods of inspection, operation, disassembly are carried on in an entirely different manner than in automobile engine practice. Aircraft engine workmanship must be of the highest grade, not only in construction but also in replacement and repairs, for when a plane starts out on a flight, engine trouble may mean the loss of life or of the plane. These things may not happen in automobile practice, for if there is engine trouble it is only necessary to get out and fix it with a loss of time only.

The service requirements for aircraft engines are quite different from automobile requirements. The requirements are much more severe, since the engine is required to operate at its maximum power constantly while in the air and the demand for reliability is much more important than for automobile engines.

All students, regardless of ratings, must report for duty at the appointed time each day. They must appear in dungarees, and must enter the laboratory in formation according to Navy regulations, standing at attention for roll, called by the class leader. The class leader shall report his section to the leading instructor and receive his orders as to the assigning of the men to their work. As soon as this is accomplished the class leader's responsibility ceases. The leading instructor will divide the section into squads of not less than four nor more than five men. He will then assign one instructor to each squad. This instructor will have complete charge of his squad for their entire time in the laboratory. The instructor will assign a foreman daily from the men in the squad. This foreman is to have complete charge of the men for that day and is to carry on the work as he would were he in charge of work at an air station.

The foreman has complete charge under the instructor irrespective of his rating, or the rating of the men in the squad. The instructor now acts only in an advisory capacity or as superintendent directing the foreman who is to carry out his orders.

The students must coöperate at all times and shall carry out the work assigned to them. They must perform their duties as they would were

they doing the same work on an air station. Any student finding it necessary to leave at any time must first report to his foreman who in turn will make request to the instructor. Requests for liberty must be approved by the leading instructor and supervising instructor.

The instructor must be on duty at all times in order to direct the work and also to observe the men. He will report each day in writing, the attitude, industry and ability of each man as he has observed it during that day. This report will be handed to the leading instructor to be filed and used in preparing the final report on each student.

The toolroom is constructed and run on a scheme similar to that of a modern manufacturing concern, and contains a standard line of tools, toolroom equipment, spare parts and special aircraft engine tools. The storekeeper has complete charge of the toolroom and will issue checks to each foreman who in turn will sign for them. All tools must be turned in every night before the section will be dismissed: al tools and checks must be accounted for.

At the conclusion of this laboratory course all checks and tools must be accounted for and the foreman must show a release slip signed by the storekeeper and the leading instructor. At the end of each day, time will be allowed for gathering tools and returning them to the toolroom. Engines must be covered each night with canvass. Attention is drawn to the fire extinguishers in the laboratory in case they are needed.

A very thorough inspection of the engine and its accessories is to be made in conformity with detailed instructions which are given later. After inspection, the engine is started and is operated for about 15 min., according to the detailed instructions, noting temperature and pressure of lubricating oil and of cooling water, and also noting the engine speed. Next, the engine is removed from its operating stand and is put on the assembly stand. The oil is drained from the engine and the engine dismantled, with the exception of pistons, connecting rods, crankshaft and bearings. All parts are inspected, cleaned and tagged. Details of procedure will be taken up later. Next, the engine is reassembled, all adjustments are made and the engine is secured to the testing stand and made ready for operation. Before the engine is started it must pass the inspection of the instructor. After the engine is started it is idled for a few minutes before giving it a load. This is for the purpose of warming the engine, and while so doing, all fuel, oil and water piping is inspected for leaks. After the engine is thoroughly warmed the throttle may be opened wide, the spark fully advanced and the engine run under full load for about 5 or 10 min. If the operation is satisfactory, the engine is run at various speeds for periods of 10 min. each for determining the fuel consumption at various speeds. The results, r.p.m. vs. fuel consumption, are plotted as shown in Fig. 508.

Notes must be kept by each student during the entire engine laboratory

course. A daily log must be kept, a record made of all data and results of the tests, and also curves must be plotted as required.

Each squad spends an entire day in running a performance test of an aircraft engine, which is connected by a flexible coupling to an electric dynamometer. Fuel-consumption tests of the engine are run; (*a*) to determine the effect of change of speed; (*b*) to determine the effect of variations of load; (*c*) to determine effect of variations of needle-valve adjustment. These three tests, (*a*), (*b*) and (*c*), are run with commercial gasoline, and then with high-Baumé test gasoline, for comparison of results. The results obtained from all these tests are plotted as graphs.

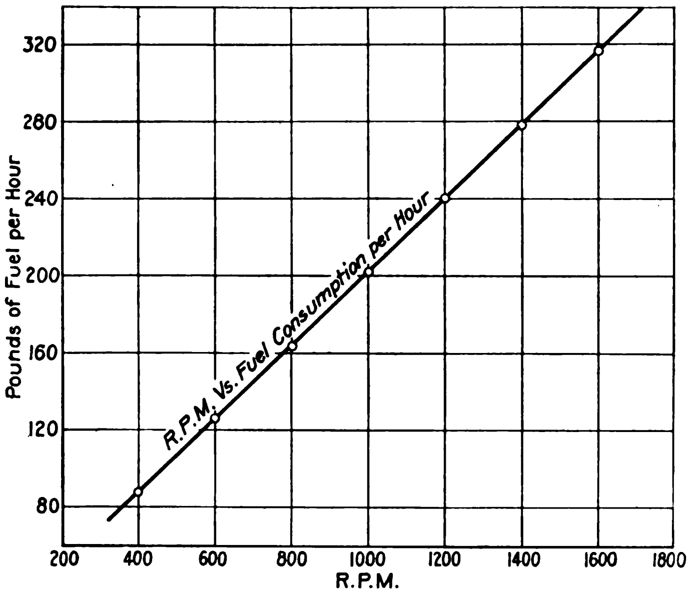

FIG. 508.—Fuel-consumption test.

The indicated horsepower of the engine is determined by the procedure which is described in detail later. From this indicated horsepower and the measured brake horsepower, the mechanical efficiency of the engine is calculated.

Practical Work on Aircraft Engines

275. Detail Inspection. Aircraft engines must be inspected periodically to determine their condition and to insure proper functioning and operating, in order to obtain maximum efficiency and service at all times.

Bolts and Nuts. All bolts and nuts on aircraft engines should be properly tightened. To inspect them, a wrench should be tried on each separately. If nuts are found that have their corners worn off from care-

less tightening with a wrench too large, determine the person that tightened them and show him how a nut should be securely tightened without defacing or damaging it. Use wrenches that fit the nuts. If using adjustable wrenches, fit them securely to the nut before attempting to turn them. Never, if avoidable, use a hammer or too great a leverage on a wrench handle. Both tend to damage the wrench, nut and stud. This rule, of course, has limitations, as in the case of very large nuts it may be impossible to get them loose or to tighten them sufficiently with a wrench of ordinary length. In such cases use a length of pipe on the handles as a lever. If that is not sufficient, have some one hold tension on the wrench and with a piece of scantling or a soft maul apply blows upon the handle of the wrench or lever. These blows are never to be applied at the end of a long lever, but at a point where it causes the least vibration in the lever handle. Any defects found, such as stripped threads and cracked nuts, must be noted for replacement.

Never try to force a nut on a stud if it does not turn freely. Examine for burrs, size and pitch of thread. A U. S. Standard, S.A.E., or a metric thread will not match. Do not force them even though there is only a difference of one quarter of a thread in an inch. Never finally tighten a castellated nut without lining it up for the cotter-pin hole. Never back off a nut to make this hole match. If it cannot be made to match, try another nut; if not then successful, use a washer of different thickness or grind some off the face of the nut. This latter is an undesirable method and should be avoided as much as possible. If a lathe is available, face off the nut. This keeps the face or friction surface true and makes the nut less likely to loosen.

Cotter Pins. Insert cotter pins that fit or nearly fit the holes. The eye of the cotter pin should be turned so it will slip flatwise into the castellation of the nut. If the pin is too long in the beginning, cut off with wire cutters, so that the opening end of the cotter when opened will be neat. The ends should be crimped up close to the nut so that they will not cut the mechanic's hands, not catch in the clothing. Sometimes bolts that should be cottered appear to have no holes for cotters. Closer examination shows that these holes are filled with the body of a sheared cotter pin. Drive out this sheared portion, and replace with a good pin. Cotter pins placed in pin holes of bolts that extend above the slot installations of the nut are of little use. A shorter bolt should be used in this case.

Fuel, Oil and Water Systems. Students must familiarize themselves with the fuel, oil and water systems.

Fuel System. Starting at the gasoline tank, follow the line to the fuel strainer, stopcock and carburetor. All joints should be sweated or soldered and the unions should be secure and have proper gaskets in them. Any leaks in joints, fittings, or cracks in pipes or fittings must be located and properly overcome. Disconnect the fuel line at the carbu-

retor end, open the bypass and blowout with compressed air. Turn on gas to see if it flows clear, then shut it off. Reconnect the fuel line if all right. Eliminate short bends when possible.

Oil System. Tracing the oil line through an aircraft engine does not consist of tracing with the eye a series of external pipes. To trace the oil line of an engine is meant that the student, having formerly made himself familiar with the system from drawings and actual work on the engine, should describe for the particular engine in question, the course of the oil through it; beginning at the sump, or outside oil tank, and telling in order where it goes, step by step, through the system and finally returning to the tank or sump. The condition of these passages can only be known by observing the oil gage when the engine is running.

There are few places on an assembled engine where the oil line can be reached. Hence, if the oil pressure fails to come up to the proper amount, by a dangerous margin, and the few accessible places in the system are not adequate to remedy the fault, the engine should be torn down and all oil passages properly opened. Give particular attention to the little tube that runs up from the crankshaft to the camshaft housing on several standard American engines. This tube, if loose, tends to vibrate resulting in the final breaking of a joint. If this were to happen with an engine in a plane, serious damage may result, as the cams, rockers and gears cannot run long without an oil supply. This rather delicate tube forms the total source of supply.

Water System. The water system must be traced from the radiator to the pump, pump to cylinder jackets, cylinder jackets to return manifold, and from there back to the radiator. All joints must be tight and leakproof. No unduly worn or cracked hose connections should be allowed to remain. See that all fittings about the engines are good, and that leaks in jackets or radiators are located and remedied.

On flange joints good packing material should be used, heavy shellacked paper serves this purpose very well. Hose joints should be whiteleaded. Lapped joints should be cleaned well and no gaskets used. In the case of hose used for connections, wrap this hose with friction tape, and shellac. This prevents the hose clamps from cutting it, and prevents oil from rotting it. Shellac on the inside of the hose often makes it hard to remove and for that reason should not be used. Often the metal connections are badly damaged from prying off shellacked hose connections. See that water-pump packing around the driveshaft is not leaking, and that it is not unduly tight. Water connections to the carburetor-manifold jacket should be examined when other water connections are examined.

To determine the character of the fuel at hand proceed as follows: Drain out a small quantity of gasoline for a specific gravity reading, and ascertain if there is any water or foreign matter in it. This sample

of gasoline should be drawn from a low place in the fuel line, preferably the petcock on the strainer, for if there is water in the line it will flow to the lowest level. Remove all foreign matter and water from the sediment cup.

The oil gage should be tried to see that it functions properly. The amount of oil pressure registered by it should be noted. Make sure that all tanks, sumps and passages are free from sediment. Use the proper oil as specified for the engine, and, if the means are at hand, determine the viscosity of the oil. Never allow an engine to go on test with contaminated oil in it. Oil should not be allowed to remain in the system for more than 6 or 8 hr. running time, after the oil has remained in an engine system for this length of time, it should be removed and run through an oil reclaimer. The oil level should be kept as nearly correct as possible, but it is better to keep it too high than too low. If smoke issues from the exhaust draw off a little oil until the smoking ceases.

The radiator must be full of fresh water, free from all foreign matter. Care must be taken to see that no chips or other foreign matter gets into the cooling system while filling the radiator.

Inspection of Carburetor. The float must be examined and inspected for puncture or leaky seams. To determine the location of any leaks, submerge the float in hot water; if small bubbles come to the surface, notice closely where they come from. Turn the float in several positions for this test. If any leaks are found in the seams solder them over as smoothly as possible. First, drain off the gasoline that has leaked into the float by puncturing a small hole at a point not on a seam, nor on the flat ends, but around the barrel, as it will drain more easily. When thoroughly drained, solder this hole.

Examine needle valve and seat for proper seating, make sure the valve mechanism works freely, and that the needle valve is not bent. If the valve is straight and leaks occur, grind the valve to its seat, using fine emery and oil or fine grinding compound. When the seat appears to be well ground, test it with some gasoline to make sure it does not leak. If leaks occur, grind the valve a little more and test. Do not stop grinding until the valve holds gasoline perfectly.

Remove the strainer from the carburetor and clean it thoroughly. Make sure that the gauze is in good condition, and the securing solder not broken loose at any point.

Examine the jets and compensators to make sure they are of the proper size and perfectly clean. Never use wire to clean them, as it is likely to increase their size. See that they are lock-wired, as they occasionally work loose and cause trouble.

All parts should be thoroughly cleaned with gasoline and wiped dry before assembling.

Blow out all parts carefully with compressed air to make sure that inaccessible parts are cleaned.

Examine the throttle and see if it operates properly throughout its full range. If there is more than one carburetor, make sure that the butterfly valves in all carburetors are synchronized. Make sure that the throttle rod has a full range of action.

Close examination must be made of the butterflies to see that all moving parts connected with carburetor permit the butterflies to open and close properly. Bent clevice pins often cause the connections to move only part of their entire range of travel.

In inspecting carburetors, care must be taken to see that all are properly adjusted. Adjust relative proportions of air to gasoline according to weather conditions before pronouncing the carburetor adjustment correct. Having made sure that the adjustments are correct, proceed to check the synchronization of both carburetors as follows: Loosen the adjusting screws and have both butterflies closed tightly; tighten the clamps connecting both carburetors and secure them properly. This adjustment having been completed, manipulate hand-control lever and observe the connections to see if the butterflies open at the same time.

Direction of Rotation of Engine. If in doubt as to the direction of an engine's rotation, rotate its crankshaft and watch the action of the valves. If, at the closing of the exhaust valve the intake valve immediately opens, the crankshaft is being rotated in its normal direction.

If the magneto is disconnected, trace the gearing to determine its rotation. Try the magneto to check its rotation, by seeing which direction of its rotor causes the better spark. Check this against advance and retard positions. The result, checked through the gearing, proves the engine's rotation.

The direction of armature rotation may also be determined by removing the breaker-box caps on the magneto, and noting the direction in which the cam travels relative to the breaker lever; its construction and the position of the spring in closing and opening the interrupter points.

Observe the installation of the engine in the plane. The tractor type has the propeller in front of the wings, and the pusher type has its propeller aft of the wings. To determine the rotation of the engine from the propeller, observe the flat side of the blade. The propeller advances through the air like a screw. The pitch of a propeller is the distance which it will move ahead in one full revolution if there were no air slippage. The direction of rotation can also be determined by tracing the gearing that drives the water pump, also noting the water line from pump to cylinder, and radiator to pump.

Water enters the inlet pipe and comes in contact with the fast turning

rotor, which, due to a strong centrifugal force, causes the water to pass out of the tangent outlet to the cooling jackets. The hand-starting

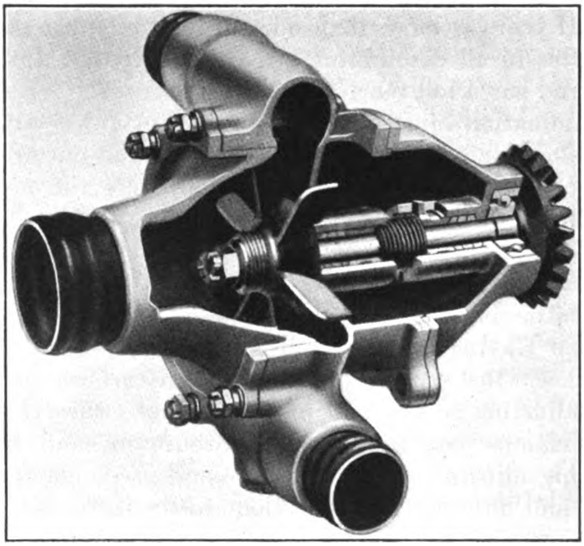

FIG. 509.—Water pump.

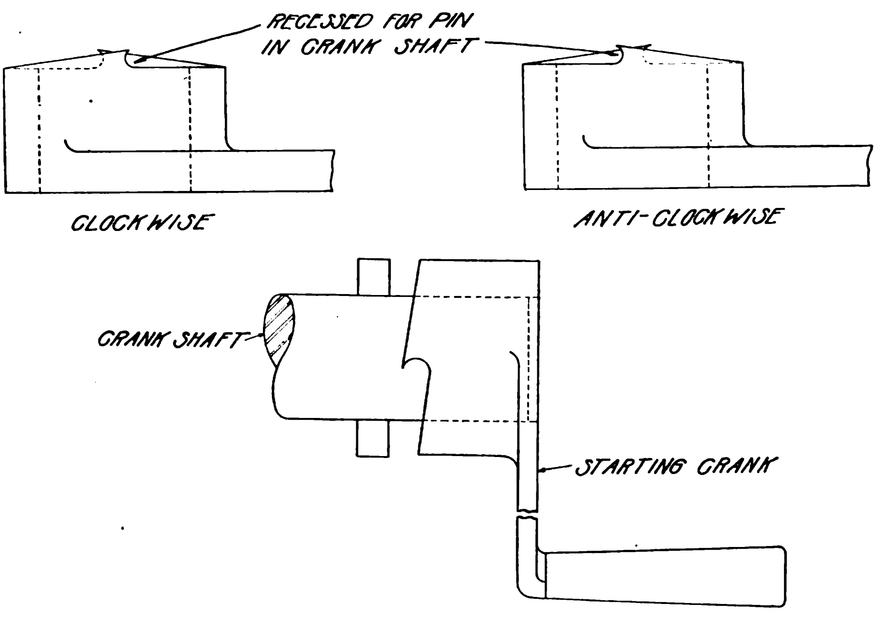

FIG. 510.—Hand-starting crank.

device on the crank also shows the direction of the engine's rotation, by the way the ratchet teeth are cut. See Fig. 510.

Firing Order of Engine. Inspection for the firing order should proceed as follows: Note the firing order from the valves, either inlet or exhaust, as the engine is cranked over two revolutions. The order in which the inlet or exhaust valves, open or close, is the firing order of the engine.

Valve Clearances. Start with No. 1 cylinder and turn to T.D.C. of the firing stroke. Then, with a set of feelers, measure the tappet

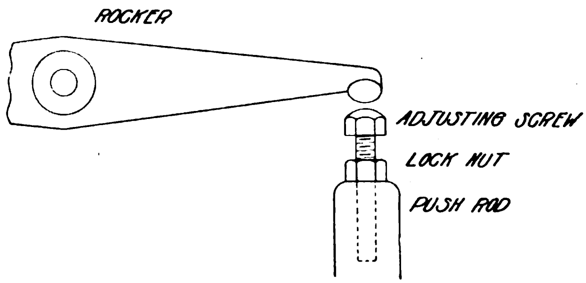

FIG. 511.—Push rod adjustment.

clearances of both inlet and exhaust valves. By following out the firing order the clearances can be checked in two revolutions of the crankshaft.

A degree plate can be used to give the proper valve-checking position, but finding T.D.C. with a rod through a spark-plug hole serves the purpose just as well.

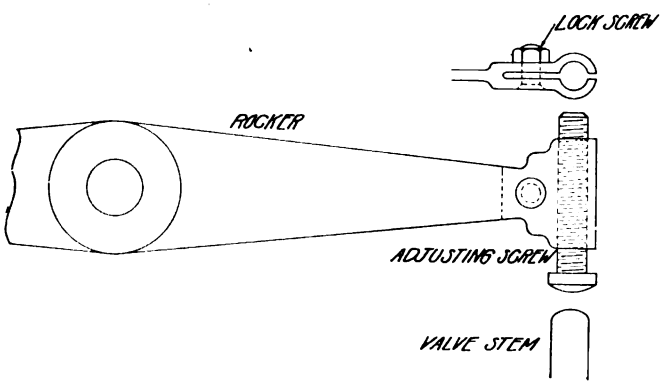

FIG. 512.—Rocker-arm adjustment with lock-nut.

After the clearances are set to the standard for that type of engine, place on the degree plate and check all valve actions to see that they are correct. If all valves open too late or too early, the timing of the camshaft is wrong; but if one or two valves have imperfections in their action, it is an indication of a worn or improperly cut cam. In cases where this causes serious faults in the valve action the clearance adjust-

ment is resorted to in the correction of this fault. Clearances should not be set when engine is cold and allowed to be used as they are. The engine should be run after they are set, after which they should be again checked.

There are various means for varying the valve clearances such as varying a screw in the rocker arm, placing shims under the valve tappets or varying the length of the push-rods. The push-rod type is adjusted by loosening the lock-nut and screwing the screw in the end of the push-rod either in or out. See Fig. 511.

The rocker-arm adjustment is made similar to the push-rod adjustment, except for the fact that the screw is either locked with a screw or a lock-nut as in Fig. 512.

The shim adjustment is made by placing shims of various thickness under the tappet bolt, as in Fig. 513.

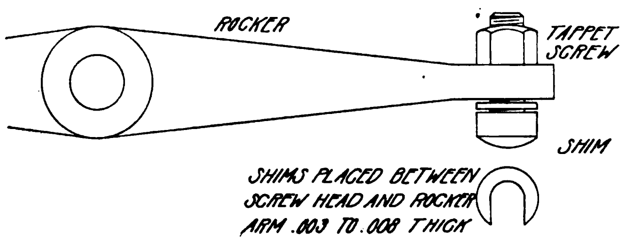

Fig. 513.—Rocker-arm adjustment with shims.

Time of Opening and Closing of Inlet and Exhaust Valves. To locate T.D.C., place a smooth rod on top of the piston through the spark plug hole and rotate the crank until the piston is about 1 in. from the top of its stroke. With a file or scriber locate a point on the rod with respect to the top of the spark-plug hole. With a trammel or a large pair of dividers centered on some permanent point, such as the floor, engine stand or a stationary part of the engine itself, scribe an arc on the periphery of the propeller hub. Then rotate the crank until the piston passes T.D.C. and travels down a distance equal to the original setting, which condition will exist when the mark on the rod is in the same relative position with the spark-plug hole as it was when scribed. Scribe an arc on the periphery of the propeller hub using the same radius and center as before. Bisect the distance between the two arcs on the hub. With the trammel centered on the same point as was previously used, rotate the crank until the bisecting line coincides with the other trammel point. The piston is now located at exactly T.D.C.

After locating T.D.C. place the timing disk in position and proceed to check the opening and closing of the valves by it.

On some engines the valve timings are stamped on the hub and no degree plate is needed. In this case it is only necessary to determine

T.D.C. for No. 1 cylinder and secure a pointer on the crankcase to point to T.D.C. on the hub. Once the pointer is set, valve actions for all cylinders can be checked.

Spark Plug and Gap. Spark plugs must be removed, thoroughly cleaned and inspected for faulty terminals, stripped or battered cylinder-connection threads, cracked or broken insulators, broken gaskets and burnt electrodes. The spark gap is then measured and reset if necessary. Spark gaps should be tried frequently, as the high temperature to which the electrodes are exposed causes them to change their gap. Spark-plug gaps should always be set to the maximum efficiency point. This can be determined from experiment during test. Some magnetos will spark over a larger gap than others. The gaps, as used with various high-tension magnetos, range from .150 in. to .300 in. A whitish appearance of the electrodes is a good indication of the gap being adjusted to the proper amount; it also indicates a strong magneto.

Magneto. Inspect the magneto and clean it thoroughly. Remove the distributor block and clean it with clean gasoline and a soft rag. At times it is noticeable that segments are blackened, due to brushes. The segments can be cleaned with metal polish or powdered pumice. Never use emery.

Breaker gaps must be checked, and, if necessary, adjusted to conform with the standard for that magneto. Always keep breaker points clean.

A little vaseline should be applied to the breaker block that rides on the cam. Examine all parts of the breaker mechanism to see that none are missing, broken or corroded, and that all springs have the proper tension.

Ground wires should be inspected as to their security at terminals. Feel along the ground wire through its entire length to locate any break that might be hidden by the insulation. See that it is well grounded to the upper part of the crankcase, and that it does not chafe anywhere. A loose ground wire is very dangerous, both to the mechanic that cranks the engine, and to the pilot who must depend on it for safety of his life.

Examine the magneto to see if it has the proper amount of retard and advance. Go over all links, wires and control rods or lever to see that they are secure and in good working order. Measure the angles of advance and retard and if they are not correct, make the proper changes.

Synchronizing of magnetos should be as nearly perfect as possible to obtain best results from double ignition. Especially at high speed when the spark is advanced, the magnetos should both fire alike to get the most efficient results. To synchronize two magnetos, first, get one of them set to exact advance and retard angles, then adjust the other one just like it. Either use thin paper between the breakers or the light method. The first method is very simple. Place the paper between the breaker points,

then rotate the crankshaft in its normal direction. If both papers come out at the same time under a gentle pull, the breakers are working alike. By this method check both advance and retard positions. When using lights, remove the primary breaker lead and connect a battery and lamps, as shown in Fig. 514.

Then advance the magnetos and rotate the engine over a firing point. Both lamps should go out at the same time. If they do not, further adjustment is necessary. The retard position should be tried in the same manner.

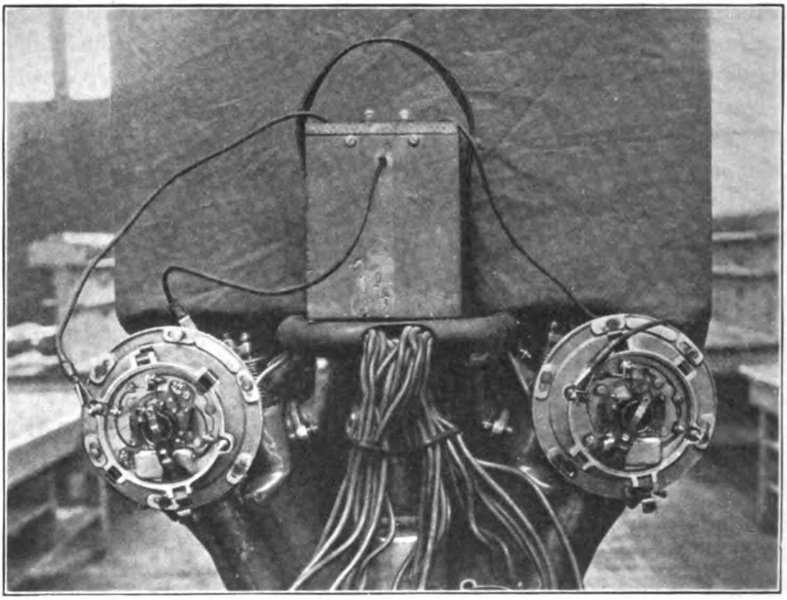

FIG. 514.—Method for synchronizing magnetos.

Wiring. All wiring must be carefully inspected for burned, worn, or oil-soaked insulations. They should be inspected for hidden breaks in the wire. All high-tension leads must be checked from distributor head to cylinders to see that they are in the proper firing order.

When two magnetos are used, one magneto should fire all inside or outside plugs for the entire engine. They should be carefully inspected to see that they are correct. In this method of wiring, if one magneto fails the other will continue to work one plug in each cylinder.

Insulation must be free from oil-soaked, charred or worn places.

Examine all terminals to see that they are clean and well secured.

With a buzzer, or bell-testing outfit, test all wires to make sure they lead to the proper places and are not short-circuited.

Defects, Logged and Corrected. All faults and defects that have been found must be neatly logged, so that a systematic correction of these defects can be made.

276. *Operation.* Examine the engine carefully to see that no tools, spare bolts, nuts, cotter pins, tape or any loose articles are laying around or on the engine, and that there are no loose terminal connections. See that the propeller or club is properly secured and that there are no obstructions to hinder its rotation.

The protection doors or encasements must be closed and wired. The rocker arms or cam-follower guides and other external oiling places on the engine should be oiled. Be sure that the required amount of oil is in the sump; then, open all valves in the oil and water lines.

There may be some difficulty in deciding in which position the spark lever is advanced or retarded. If in doubt, remove the cover from the breaker-box to determine its position relative to advance or retard. The engine should be started with the spark in the retarded position. If started in the advanced position, the engine is likely to backfire and cause backward rotation. If a crank starter is used and the engine starts rotating in the reverse direction it may cause injury to the person starting the machine.

The fuel line should be checked and if there are no leaks at any of the joints or couplings, the valve may be opened allowing the fuel to flow to the carburetor. Raising the needle valve or float and allowing the fuel level to rise in the float chamber will assist in supplying the rich fuel-air ratio necessary for starting. With the spark or switch in the "off" position, and the air inlet to the carburetor closed, rotate the crankshaft one revolution and a charge of gas will be drawn into the cylinders.

The throttle should now be set so that the butterfly valve is slightly open. It should be opened sufficiently, so that when started the engine will operate at an idling speed of from 400 to 600 r.p.m., depending on the type of engine.

The ground switch is now opened and the engine is ready to be started either by a mechanical starter or by cranking. If cranked by hand care must be taken to see that the dogs or clutches mesh properly. Rotate the crankshaft slowly until compression in a cylinder is felt; then quickly rotate the crank which should cause the engine to start. Air and electric starters have also been used satisfactorily on engines.

After the engine has been started it should be operated at from 350 to 500 r.p.m. until thoroughly warmed, that is, the oil, water and metal parts are at or near their normal operating temperatures. If this is not done, to the unequal expansion, excessive stresses may be set up which may cause the water jackets to leak or other parts to become distorted and cause trouble. Also if the oil is not heated sufficiently it may be so

thick that it will not reach the journals and cylinder walls in sufficient quantities to prevent burned bearings or scored cylinders and pistons.

To prevent the battery from being discharged while the Liberty engine is being operated at speeds below 600 r.p.m. it must be operated on single ignition. Above 600 r.p.m. the generator voltage equals or exceeds the battery voltage. Therefore, both switches may be thrown on causing the machine to operate on double ignition; at the same time the generator will supply the ignition current and if the speed is high enough will also charge the battery.

While the engine is running idle, the water circulation should be examined to see that it is working properly and that no part of the engine is getting too warm. The oiling system and the oil pressure should also be examined. If anything seems to be at fault the engine should be stopped. However, if the engine functions properly the speed may be gradually increased. The engine should be accelerated occasionally in order that the reciprocating parts may be properly and thoroughly oiled.

The oil pressure is likely to be very high when the engine is started, as both the engine and oil are cold. The oil pressure will increase gradually until the pressure has reached its maximum at the highest speed. If it is noted that the pressure does not increase with an increase in rotative speed, the trouble should be located before operating the engine for any length of time, for operation in this condition may result in burning out the bearings or causing other serious damage to the working parts. If the pressure is too high, it can usually be regulated by adjusting a relief valve or by a compression spring. The oil pressure gage is important to watch, and if the pressure is seen to drop suddenly the engine should immediately be stopped and the trouble located. Engines vary in rotative speed, clearances, construction and materials used. Therefore the grade of oil and normal oil pressures vary. Some engines require a low pressure, and others a higher pressure, depending upon the clearances and the type of lubricating system employed.

The temperature of the water also, should be watched. Water temperature should be between 150° and 180° F. if the engine is to operate properly at wide open throttle. Should the temperature go any higher than this, the system should be inspected and the necessary repairs made.

An engine that has run for 5 or 10 minutes has had sufficient time to warm up and permits a higher rate of speed. Before being thoroughly warmed up, it may be necessary to shut down the engine to make various minor adjustments such as varying the idling jets in the carburetors to give the proper mixture. With the engine running idle and the spark retarded it is easy to detect skipping or misfiring of the cylinders. However, running the engine in this manner causes it to heat excessively and should not be continued for any length of time. After the engine is thoroughly warmed and running well, check the gages for pressure and

temperature. If all are within their proper limits, it is permissible to run at various throttle positions to make the necessary carburetor adjustments.

While the engine is running, notes should be made of all oil, water, and fuel leaks. Leaks in the water line should be looked for at all the connections in both the inlet and outlet line and at places where water connections are between the cylinders. Sometimes, the presence of rust is noticed at different places, although no water may be seen. It is a good indication of a leak which should be properly stopped by tightening the connections or replacing the gaskets. It may be necessary to change the hose connections. Particular attention should be given to the oil leaks. Permanent repairs should be made as the consumption of oil is greatly increased by such leaks. Where long flights are planned a very small leak may cause an early descent. If leaks are in the supply lines a decrease in pressure will result. These leaks may sometimes be detected by watching the gages.

Oil leaks are found on some types of engines, due to improper fit at the pad where the valve mechanism covers are secured. Connections are often made with the threads crossed or stripped. These connections should be replaced or soldered.

At the flange where the two halves of the crankcase are bolted together, leaks are often found, especially when the joints are poorly lapped. Leaks are often found at the thrust-bearing end of the engine. Piston ring oil leaks may sometimes be detected by the presence of smoke. If the leaks are serious the engine should be stopped immediately. All small leaks may be noted and repaired when the engine is not running.

All other defects that may show up during the operation of the engine should be corrected before the engine is again operated.

With all necessary repairs and adjustments made, the engine should again be started in the manner as previously described. Having noted all gages for pressure and temperature with the engine operating properly, increase the speed until the maximum-rated engine speed is reached.

With the ignition and carburetor properly adjusted so that no skipping or backfiring is noticed during acceleration, the engine should be run with wide open throttle for 10 min. While operating in this manner either of the ignition banks may be cut out to see if any change appears in the engine's running or speed. Usually a slight decrease in the speed will be noticed, which will vary from 10 to 150 r.p.m. depending on the engine. Occasionally when one ignition set is cut out skipping will result, which indicates faulty ignition on the set of operating plugs. The same procedure should be followed on the remaining bank.

The water temperature should again be noted while the engine is running with wide open throttle, not allowing the temperature to go

above 170° F. or below 150° F. during the operation. Also, note the temperature of the oil. Do not allow it to rise above 130° F.

The oil-pressure gage must also be watched. This helps to show whether or not a constant flow of oil is maintained and how the lubricating mechanism is working. Faulty operation of this mechanism would immediately be shown on the pressure gage. On various types of engines the pressure ranges from 7 to 90 lb., depending on the design.

Gages used in connection with aircraft engines are as follows: Tachometer, oil-pressure, oil-temperature, and water-temperature gages. These gages are essential to show the actual running condition of the engine. It is important to inspect and keep these gages clean and in perfect working condition, as they are the means of finding most engine troubles and help to diagnose the various defects. Engine performance notes always include the gage readings and various deductions are drawn from the readings.

277. Disassembly. The disassembly and assembly of aircraft engines, in general, varies with design and type. The general procedure of engine disassembly will be covered. Engines have been designed with camshafts in the crankcase, others have the camshaft mounted on top of the cylinders. Engines also vary as to the design and type of valve-operating mechanism. Other engines vary as to the method of securing the cylinders to the crankcase. Some cylinders designed are en bloc, and others separate. Detailed instructions regarding the fastening of cylinders will be treated under the instructions for handling each individual type of engine.

Disassembling. All fuel and oil supply-line valves must be shut off before draining the water and oil. Care must be taken that the water is drained from the lowest drain on the engine. Disconnect the fuel, oil, water, and tachometer lines. Ignition wires must be removed from batteries. The propeller or club must be removed from the hub. This much accomplished, inspect the engine for any other details regarding accessory connections which might retain the engine in the frame.

With the engine clear of all connections it is jacked or hoisted up and placed on skids to which the engine is bolted when the skids are in their proper position. The engine is then carried to the teardown stand, which is constructed so that the engine, while being assembled, can be turned upside down or in any other position. In shops where overhead trolleys are employed, the engine is hoisted, necessary care being taken not to let the rope or chains chafe the engines parts. It is conveyed by trolley to the disassembly stand and fastened by bolting down, in the same manner as on the test stand or fuselage. Having made sure that the engine is properly fastened, turn it over with the aid of the revolving mechanism attached to the stand.

The squad assigned to an engine proceeds to dismantle the engine,

working on both sides of it. Each student works on some particular part under the direction of the squad foreman. The necessary tools are laid out within easy reach. Engines are generally disassembled in the following manner:

Remove carburetors and magnetos. In cases where two are employed, care must be taken to keep them identified. A good plan is to tag each one, marking its position on the engine. This saves time when engine is to be assembled.

Remove all spark plugs, care being exercised that the wrench does not slip, causing the porcelain to be cracked or broken. The water inlet and outlet lines are then removed. Care must be taken that they are not damaged by dropping or bending. This care must also be observed when the manifolds are removed. Mark them for their respective positions. It is good policy to mark the timing-gear mechanism, when the covers or casings are removed. Look for the manufacturer's marks by rotating the crankshaft. This applies to engines that have the camshaft in the crankcase. On engines where the camshaft is mounted on the top of cylinders, the vertical driveshaft cover is removed to ascertain the gear setting. The driveshaft on the overhead camshaft type of engine is then disconnected and camshaft-housing hold-down bolts removed, after which the camshaft can be removed.

Remove the oil and water pumps, making note of defective fittings and parts that may need repair or replacement. This is essential as new parts may have to be ordered or made. Remove the cylinder hold-down nuts or bolts. Take off cylinders, being careful that the piston does not strike against studs or crankcase, thereby damaging the piston or the piston rings. Small pieces of rubber hose placed over the studs reduce the possibility of such damage. If the engine is one in which the main-bearing caps are fastened to the upper half of the crankcase, it can be turned over and the lower case taken off.

With the engine disassembled down to the crankshaft, with connecting rods and pistons attached, remove the complete crankshaft assembly from the case and inspect the condition of the shaft. Also inspect all bearings remaining in the two halves of the case to see if they are pitted, scored or cracked. Also look for mental flaws, as these often appear as fine scratches. If overlooked and used in that condition they will often cause a bearing to be ruined. The babbit starts to loosen at this flaw and rolls up in the direction of crankshaft rotation. All parts must be inspected thoroughly and conditions noted.

The crankshaft assembly is next disassembled, removing connecting rods, replacing caps on rods in the same position as taken off. Then remove the wristpin retainers and wristpin, and place piston where no damage can be done to it. Inspect connecting-rod bearings and note all defects

The cylinders should be inspected for scores and measured by inside micrometer for variations in size at top or bottom and for eccentricity. Also check the cylinders to ascertain if the bore is correct or out of shape, caused by overheating and strain while in operation. The pistons are also measured at the top and bottom to see if they have the proper amount of taper and clearance. Different engines have different clearances allowed. These should be checked up according to manufacturer's specifications. After it is found that a piston is out-of-round it may be reshaped by the simple device shown in Fig. 515. The piston is placed in the jig and a slight pressure applied at the handle A, care being taken that the pressure is not too great. B, is a hinge that permits the upper half of the jig to be lifted, and brought back into position. Having reshaped the piston, it is necessary to measure it again. It is often found that a piston is too badly worn to permit reshaping. This necessitates replacing that piston with a new one. Wristpins are measured to see if they are worn or if the bushings are worn. Crankshaft pins are next measured with a micrometer for proper diameter and roundness.

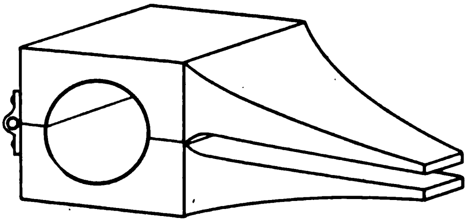

FIG. 515.—Jig for straightening pistons.

The shaft is placed in V-blocks set upon a surface plate. A surface gage or vernier height gage is used to determine if the shaft is sprung. This can also be done by placing the crankshaft between true centers as in a lathe. Be sure that the oil passage in the crankshaft is clear and clean.

When cylinder and piston measurements have been taken they are compared to determine the clearances. In all cases, a record must be kept of each part.

The camshaft is removed from its housing and a thorough inspection made of all bearings and journals for looseness and end-play. Cams must be examined for hardness, rough edges, and undue wear caused by riding of cam followers. If rough they are to be stoned with a smooth oil stone and a report made of each one found in this condition.

All machine finished, polished or enameled parts must be thoroughly washed in gasoline or kerosene. Careful inspection for breaks, cracks, or flaws must be made before the parts are oiled or coated with grease. This treatment protects the parts from rust and corrosion due to dampness.

All parts should be placed on a rack or shelf according to the order

in which they were taken from the engine, and on the side of engine from which they were taken. This means a saving in time when the engine is to be assembled after necessary repairs have been made.

With complete notes of the condition of the different parts, a recorded report is given the instructor of the squad. Each man in the squad keeps a general log and this is retained in his private notes. The instructor examines each man's notes and makes the necessary corrections each day during the work.

278. Fitting and Adjusting. With the data obtained while dismantling the engine, the members of the squad start in refitting, repairing, and adjusting the clearances of the subassemblies. For example, one man starts to grind the valves to the cylinders; another takes the camshaft and housing and fits the bearings to the shaft and housing. The remaining men in the squad will fit the crankshaft, scraping or replacing bearings where necessary. The crankshaft should have an 80 per cent. minimum bearing surface when finished. The men will interchange jobs throughout this work in order that each may become familiar with all parts of the engine.

The crankshafts are "spotted in" and the bearings scraped, where needed. Care is taken in order that the proper clearances are given to the main bearings and that the clearance varies with the different makes of engines. The following parts should be carefully checked for clearances.

The piston pin to the piston; the piston rings to the piston; the connecting rods to crank, also all end clearances; crankshaft to the case or main bearings and also end-play for it; the bearings to the camshaft with the proper side clearance; where overhead camshaft is used, the rocker arms should have the proper amount of clearance.

By referring to the log or data taken while disassembling or inspecting the engine parts, it will be easy to determine what new parts or replacements are necessary. Replacement of new parts often means the fitting of that part, since sometimes the part is left a little over-size. On some occasions parts of the engine may be broken when no spare parts are obtainable. Then it is necessary that a man be a mechanic, as that part may have to be made out of rough stock. It may be necessary to do the work on a lathe, drill press, shaper, grinder or other machine tools. Therefore, the man should have a good knowledge of machine tools. Sometimes a crankcase may be cracked or some other parts broken that may be temporarily repaired by welding and made to hold until such part can be ordered, obtained and assembled.

All the hose connections should be examined and new ones made to replace those that are worn or torn. It is good practice to wind one layer of tape around the hose and shellac it. This protects the rubber from oil, which has a tendency to rot the rubber fabric. Every time an engine is overhauled or disassembled it is good practice to regrind all valves and,

test them for leaks and proper seating. To take the valves from the cylinder, it is necessary to compress the valve springs and to remove the spring locks and the spring. The valve is then free in its guide. There are different types of spring-compressing arrangements and many special tools, as each manufacturer has his own ideas and each tool is probably equally odd for a specific engine.

The valve springs should be tested, while compressing them, by means of a spring scale. When the valves are taken out, they are often found to be in very bad condition. Some may be warped and others badly scored and pitted. If so, it may be better to replace them with new ones or, by refacing in a lathe, to regrind them to a good fit and seat, being careful not to grind to excess. It is best to grind valves as little as possible. If the valve is badly fitted do not try to remove all the pits, but grind until a good width of seat is had all the way around the valve.

Sometimes the valve seat on the cylinder is found badly pitted and grooved. In such cases, though the valves are in good condition, there will be a bad leak which must be repaired. The valve seat must be reseated To do this a tool must be made, if a standard reseating reamer is not available, that has the desired diameter and proper angle. With the valve guide used as the guide for the reseating tool, the seat is countersunk to a new face. The valve is replaced and reground to the seat by using a grinding compound of coarse emery and oil. The finish grinding is done with a finer grinding compound, which smoothes the surfaces and provides a better seating of the valve. To reseat a valve, care should be taken to keep the angle of the seat in the right position to the valve guide in order that the valve seats properly. Also care must be taken not to allow the tool to chatter, as this leaves deep grooves in the valve seat.

279. Subassembly and Assembly. Valves ground in should be tested for proper fit and leakage. This can be done by turning the cylinder upside down, when valve has been replaced, and by pouring in enough gasoline to cover the valve and seat. If any leak or improper grinding exists, they can be detected by looking into the valve ports and noting the gasoline that seeps through. The valve must be ground until it retains all gasoline. Then the valves are removed and thoroughly cleaned, as are also the valve seats and valve chambers.

Having been cleaned, the valves with springs are put in their respective places in the cylinder and secured there. Springs should be tested for pressure and length, the stronger or heavier spring is usually put on exhaust valves. Subassembly can usually be done without interfering with work on the main assembly of the engine.

Piston-ring grooves are cleaned and the rings fitted to the piston. The rings must also be tried in their cylinder for gap clearance. This is done by compressing the ring and slipping it into the cylinder.

New rings are usually slightly oversize in both diameter and thickness and therefore require fitting to both the cylinder and the piston-ring groove. They can be reduced in thickness by rubbing them on a surface plate which has been charged with an abrasive, or by placing a piece of emery cloth on the plate and rubbing the ring on the cloth. After fitting them to the piston, remove them and place each in the cylinder to check for diameter. There should be a gap between the end of the rings amounting to .018 in. to .040 in.

Piston-ring side clearances vary for the upper ring from .0025 in. to .003 in.; center ring .002 in.; if three rings are used, from .0015 in. to .002 in. is given the bottom ring. In many cases an oil or scraper ring is used, its clearance being the same as the lower ring. The rings having been cleaned, are then put in place, using a ring extractor. When using an extractor, do not put too great a stress on the ring. The rings being rather hard, are often broken in replacement, causing unnecessary delay.

Having fitted the connecting rods, they should be fixed to a plug gage or mandrel that has the proper clearance over the true crankshaft-pin size. The bearing surface should not be less than 80 per cent. Fit connecting-rod bearings for end clearance, according to manufacturer's specification.

The rod is properly cleaned and the piston attached, care being taken not to have too loose a fit of pin. A certain amount of clearance is tolerated but it should never be more than .00125 in. for connecting-rod bushing bearing. There are several methods of securing the wristpins. One is the use of set screws, that are screwed through the pin bosses into the pin. Another is the retainer or play type, which is pressed in place after the pin is in place, one on each side. These retainers have the same radius as the cylinder. Assemble entire crankshaft group. In some types of engines it is impractical to do this. A mechanic should use his own judgment regarding this operation, care being taken that the pistons are not damaged.

Having cleaned the crankcase with gasoline and having blown it out with compressed air, the engine assembly can proceed. The crankshaft is put in place, wiping out bearings and putting a liberal amount of oil in both halves of the main bearings. Do not pull up one nut or bolt tighter than the other. The nuts and bolts should be pulled up evenly. The shaft should revolve freely by hand. If the connecting rods are not on the shaft, they are next put in place, going through the same operation as on the main bearings. In some cases it is good practice to slip a thin metal band over the piston, while the connecting rod is put in place. This prevents the piston from being scratched or marred. These bands are removed when the cylinders are ready to be placed.

Clean off the lower half of the crankcase as well as the upper half that

is on the stand. Secure both halves together, locking each nut and bolt. The engine is then turned over on the stand.

Each cylinder must be provided with a good gasket or, if of the en-bloc type, one large gasket is used. The gaskets should set evenly and should have a light coating of oil. Oil should then be applied by hand to the piston and in the cylinder. Care should be taken that no dirt or metal chips are on these parts. Place the pistons in position so that they will be about half-way between the top and bottom of their stroke when the cylinder is in place. Put cylinder over piston. Care should be taken not to break the piston rings. Secure the cylinder and "make up" all the nuts evenly, and secure.

Cylinders are always aligned before being permanently secured. This is done by placing a straightedge along some flat part of the cylinders, such as the intake manifold pads or the camshaft-housing hold-down stud boss. If it is found that cylinders are all in alignment, they can be secured and locked.

If an overhead camshaft is used, it is generally assembled on the bench before installing it on the engine. Bearings are installed in their respective places. The camshaft is then placed in the housing, each bearing turned so that the retainer-screw hole will come in line with the hole in the housing. This is done when the bearings are all in position preparatory to inserting them in their proper places. Having secured the retainer screws by wire, lock-nut or split washers, it is now ready for the camshaft drive, if engine is of that type. The rocker arms and caps are put in place and secured. Caps should fit properly and should be put on the same way as a main-bearing cap. Valve clearances are checked, employing the use of a standard gage or feeler gage.

Carburetor manifolds are put on. These must not be crooked or indented and must have the proper body gaskets in place, so that manifolds will fit snugly and not permit any air leaks. Water connections are put on. All clamps must be fitted in a uniform manner. Rubber hose, when shellacked, friction taped, and shellacked again, will last much longer and also prevent clamps from cutting into the rubber.

All oil connections are now made up in their proper places. Threads are not to be crossed. In cases where a packing is used, care must be exercised that this does not kink. All piping must be clear and cleaned before installing on the engine. Carburetors are now applied to the manifolds with proper gaskets and the same precautions should be observed as when the manifolds are installed.

Magnetos or generators are set in place. In installing magnetos, they must be placed so that the marks made by the manufacturers correspond.

High-tension lead conduits are placed on the engine and fastened. Test out each lead for its proper place from cylinder to distributor block, by use of a buzzer or bell magneto.

Water and oil pumps are installed. New gaskets are usually put on these parts. Connect oil and water lines, in the usual manner. It is necessary to adjust the relief valve on the oil pump to insure proper pressure and lock it so that the pressure cannot rise or fall. This is generally done with the aid of a spring. Water-pump couplings should be in line with the part attached to engine. A good packing should be used in the water-pump shaft gland.

The timing of the engine is now carefully checked to see that the magneto is correctly timed, and that the valves open and close at the proper time according to the manufacturer's design and specifications.

A detailed inspection is again made of the engine, as described before, regarding loose nuts and defective parts. The engine is removed from the teardown stand and taken to the test stand. Having the engine set in place on the test stand, it must be leveled. This is done with a spirit level, held to some part of the engine that is parallel to the stand and has a smooth surface. When leather is used as a spacer between engine and stand, it is necessary to use metal shims to protect the leather from being cut.

In fastening the engine to the test stand, through-bolts should be used. Flat washers are to be used under the head of the bolt as well as under the nut. Connect water, fuel and oil lines and test each one again for flow and leaks.

The spark plugs are put in place after a careful inspection for gaps or broken porcelains. Usually gaps are about .017 in., unless otherwise specified.

Having ascertained by a thorough examination that the engine is ready for another run, the tank or radiator is filled with water and fuel tank filled and oil poured into the sump. In cases where a dry sump is used, the oil tank is filled and allowed to flow into the sump in order that pump may be primed.

280. Block Test. *Starting Engine.* Before testing an aircraft engine it is essential to notice its general condition. Make sure that the engine is fast to the stand, all of the engine parts are in good condition. and that all bolts and nuts are securely cotter-keyed and wired. Check the valve action to make sure of the timing. Remove all tools or loose parts from the engine and stand before starting the engine.

Examine the magnetos to see if they are properly adjusted, and that the breakers and brushes are in proper working condition; see if they break properly at the advance and retard positions and are synchronized, particularly in the advance position. Trace out the wiring from the distributor head to make sure that each wire goes to the proper plug. See that the plug gaps are properly adjusted. Make sure that all wires are in good condition and without oil-soaked or worn insulation. See that all connections are good and that no wires are permitted to hang loosely

about the engine. Make sure that the switches are properly wired and that the ground leads are secured.

Trace the fuel line to see that all joints are secure and that the piping is in good condition. Remove the trap and examine it for the presence of dirt or water. See that the carburetors are well secured, that the lever rods have proper travel, and that the jets are properly fastened. See that all passages are clear and that the float mechanism is in good order.

Turn on the fuel, being careful when priming the carburetor not to allow it to overflow, as by so doing a back-fire from the engine might cause a serious fire. Turn on the switch, retard the ignition and rotate the crankshaft a few times; sometimes this is sufficient to start the engine. If not, close the carburetor choke valve and crank the engine. If this does not start the engine, priming may be resorted to. Care must be taken, however, not to prime too freely, as scored cylinders might result or as some of this gas may leak past the pistons and into the crankcase where there is danger of its being ignited, thus causing serious damage to the engine. The throttle should be only slightly opened while starting the engine.

Warming. Start the engine, advance the spark and adjust the speed by the throttle. From 400 to 600 r.p.m. is a good warming-up speed, depending, of course, on the engine. Some engines intended for higher speeds do not operate well at the slower speeds. Hence, the working speed of an engine varies with the type of engine and good judgment of the operator.

Make sure that the water pump is functioning, and that good circulation is in effect. Feel about the engine for unduly hot spots that might be caused by air pockets in the water circulation. If any such are found, stop the engine if necessary and relieve them. Make sure there is sufficient oil in the system and that it is circulating. This can be done by noting the gage and by slightly accelerating the engine speed. If the pressure increases with the engine speed the oil is being properly circulated.

Note the oil gage to see if the pressure climbs to the specified degree for that engine. If the gage is correct, and the pressure is lacking at high speed, trouble exists in the system. It may be due to improper oil, clogged oil passages, clogged strainer, faulty pump, or improperly adjusted regulator. Make sure of the regulator adjustment first if such trouble exists. Do not expect the same oil pressure at low speeds that is attained at high speeds.

Water Temperature. When the engine is thoroughly heated, gradually increase the speed until full speed is reached; let it run a few minutes and then gradually slow it down. The water circulation should be such that the thermometer shows not more than 190° F. For actual operation

the temperature should be kept between 150° F. and 190° F. If the water gets hotter than 190° F. on the test stand, look for the cause. Allow more cold water to run into the system if necessary, or examine the pump to see if it is the seat of the trouble.

If possible, take the temperature of the water both before entering and at leaving the engine jackets. Compare the temperature with data referring to the same type of engine. If the comparison is not favorable look for the cause. Perhaps, the tanks are too small, or the trouble is caused by some condition outside the engine itself.

Run the engine at high speed until thoroughly heated. Check leaks and defects presenting themselves.

Timing. Stop the engine, shut off the fuel supply and stop the water circulation to the water tank from outside sources. Quickly check the valve clearances in two revolutions of the crankshaft, carefully logging the results. This should be done in the firing order of the engine, beginning at No. 1 cylinder. Check clearances of both valves at T.D.C. of the power stroke, then move to this position in each cylinder in the firing order. When the last cylinder is checked, the crankshaft will have completed two complete revolutions. Remove a spark plug from each cylinder to avoid compression. This also is a *safety first* principle as it prevents all possible chance of the engine kicking or starting from unexpected causes.

While the engine is still hot make clearance adjustments to conform with those best adaptable to that type of engine. If this alteration does not have the desired effect upon the functioning of the engine, there is a chance that the timing may be inaccurate. There may be a cam machined inaccurately or worn due to a soft spot in the metal. If this is suspected check all valve actions very carefully, using a degree plate. When the valves open too late, due to inaccurately cut cams, try to get an average on the opening and closing by adjusting the clearance. This also applies to a valve opening early.

Leaks and other minute defects, noted as incorrect during the run, should be remedied next. Great care must be exercised that all repairs and adjustments are made according to the record kept of the previous run. The carburetor or magneto is next adjusted. Check valve timing.

Start the engine as previously explained, and run it idle until thoroughly warmed. Gradually increase the speed up to the maximum. This speed should be continued for 10 minutes. The man operating the engine must pay strict attention to the instrument board, noting the oil pressure and temperatures of water and oil so as to keep them within their proper range.

Strict attention must be given to the oil-temperature gage to note the increase of temperature of the lubricant. The average increase in temperature for an engine which is in good operating condition is about

3° F. for every 100 revolutions. If the engine shows 88° F. at 800 r.p.m., at 1,200 r.p.m. the gage should show an increase of about 12° F., or 100° F. The temperature increase depends on the oil used and on the general engine conditions.

Fuel Consumption vs. Speed. When making a test for fuel consumption, great care must be exercised that all leaks are stopped in order that the engine may be given a fair test. There are various ways in which the consumption of the fuel can be determined. The gasoline tank may be placed on a scale and at intervals during the run readings are taken. These readings are logged, and by subtracting each reading from the one preceding, the gas consumption between readings is obtained. By subtracting the last or final reading from the first reading the total consumption during the run can be obtained.

Another very good way of determining the fuel consumption is to use a tank having a gage glass on it. Secure a scale, which is graduated in sixteenths of an inch, to the glass. Then determine the cross-sectional area of the tank in square inches. Consign one man to read this scale. At each reading interval it is his duty to make note of the inches, or fractions of inches, used for that interval of the run. These gage readings in inches multiplied by the cross-sectional area of the tank will give the gas consumption in cubic inches used during each interval. If the specific gravity of the fuel is known, the weight of the gasoline is found as follows: sp. gr. × .0362 = weight of 1 cu. in. of gasoline *of that specific gravity.* (.0362 is the weight of 1 cu. in. of water). Having the weight of 1 cu. in. of the gasoline, multiply it by the cubic inches used for each interval of the run, and find the weight in pounds of fuel used. If only the Baumé gravity of the fuel is known, the specific gravity may be obtained by using this formula:

$$\text{Sp. gr.} = \frac{140}{130 + \text{Bé}}$$

If a cylindrical tank is used, find the area by the formula, πd^2. Do not use the outside diameter of the tank. Tanks of irregular shapes cannot easily be calculated by these cubic volume methods.

To check the correctness of the scale-calculating method, a standard-size measure of gasoline may be drawn off, the scale reading recorded, and the volume and weight calculated. If the weight of the gasoline agrees with the computed weight the tank has been correctly calibrated. With all preparations for the *speed vs. consumption* test completed, proceed as follows: Start the engine, idle until thoroughly warmed and make any necessary adjustments, being sure that the engine is in perfect running order before proceeding with the test. A series of 10-minute tests should be made at different speeds.

The first test will be run at the idling speed of 400 to 600 r.p.m., depending upon the engine. This speed is to be maintained for 10 minutes and

readings taken. When the word to start is given, the throttle is set for the required speed and the scale on the tank's gage glass is read. At the conclusion of the time interval the time-keeper gives the signal to take the reading.

Readings of inlet and outlet cooling water temperature and lubricating oil pressure should be recorded, as these items bear directly upon the performance of the engine. When all readings have been taken and recorded, the operator increases the speed to 600 r.p.m., or the next desired speed. This speed is maintained for another 10 min. and readings

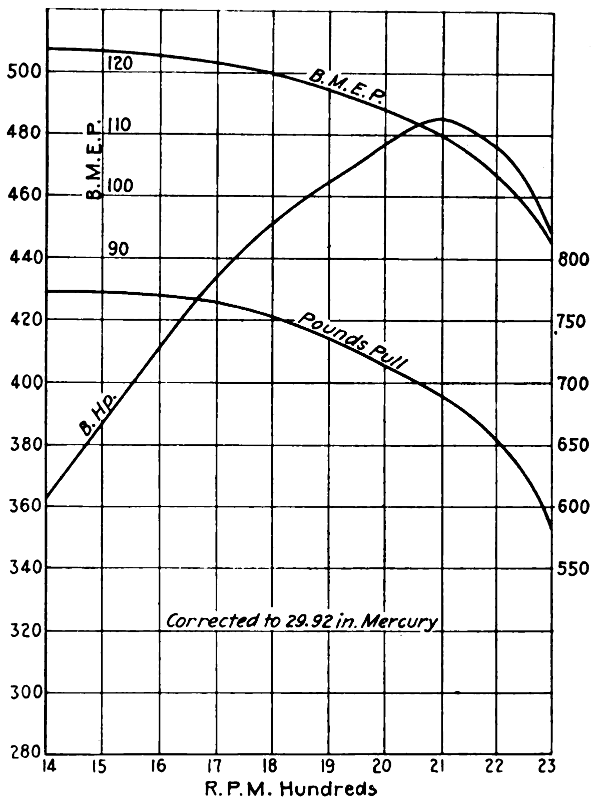

FIG. 517.—Speed in hundreds.

taken as before. Proceed in this manner, increasing the speed in steps of 200 r.p.m. each time until the maximum speed of the engine is attained. At the conclusion of the complete run, the gasoline weight for each 10 min. can be resolved into weight of fuel consumed per hour by multiplying by 6.

When all computations have been made and the results, together with the readings, have been recorded in the log, Fig. 516, a curve can be plotted between speed as abscissa and fuel consumption as ordinate. Such a chart is shown in Fig. 517.

The curve shows that the total fuels consumption increases slightly as the throttle is opened, and continues to rise at an increasing rate up to the point of maximum power.

Practical Work on Liberty Engine.

281. Detail Inspection. In tightening a nut, stud or screw its size and use must be considered. Never tighten it enough to strip or pull the threads. Some bolts will stretch.

Cotter pins should not be used on a stud or bolt when the pin hole is above the nuts castellation. This prevents nut from coming off, but does not keep the nut secured in place. Cotter pins must not be used when the castellation in the nut is broken. Cotter pins must be of the proper size, the heads are to be driven into the castellation and the ends bent around the sides of the nut. Where fillister-head screws are used, the retaining wire must be put through in such a manner that the wire will hold the screw lightly. Fig. 518 shows a fillister-head screw. *A* shows that the direction of tightening is right-handed. *B* shows the retainer wire placed in such a manner that it prevents the screw from becoming loose. This applies also in cases where set or cap screws are used with this method of locking. A permanent base must be used for fastening the wire. Loose wires will break under vibration. Where wing nuts are used, it is necessary to wire only one wing in order to hold the nut secure.

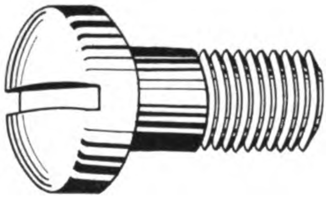

Fig. 518.—Fillister-head screw.

In using lock or jam-nuts, it is necessary to tighten the holding nut before the lock-nut is tightened. Hold the retainer nut with a wrench while tightening the lock-nut. In removing, the operation is performed by holding the retainer nut and loosening the lock-nut. Where nuts are applied to studs, the tightness of the studs can be determined by "slacking off" the lock-nut. If the stud starts to come out, it must be tightened. In tightening, get the outside end of the stud the proper height from base.

Castellated nuts are no longer used on the cylinder base of the Liberty engine. The boss, or collared nut, which is used, affords greater friction surface, eliminating the use of cotter pins.

The fuel lines on the Liberty engine must be examined very closely, due to the fact that it must often pass under or between other engine parts. The line from the tank to the carburetor must be cleaned thoroughly with gasoline and air. If a gravity feed tank is used, care must be taken to see that the vent in the tank is clear, permitting the fuel to flow freely to the carburetor. This also applies to the oil and water systems.

Any acute kinks or bends in these lines will retard the flow, and the damaged line should be repaired or replaced.

The oil pump on the Liberty engine is located on the bottom of the lower crankcase, under the front sump. The oil enters the right side of the pump, passes through the pump to the supply manifold that is located in the bottom of the crankcase. From this pipe or manifold the oil travels up to each one of the seven main bearings, passing through the crank-cheeks to the crankpins, thus permitting the lubrication of the lower connecting-rod bearings. Some of this oil is thrown out, and oils the cylinder walls. From the rear end of the main oil line the oil passes around the rear crankshaft bearing, up through a three-way connection to each camshaft housing, and to an oil pressure gage. The oil enters at the end of camshaft housing, passes through the camshaft, oiling each rocker arm, cam roller and camshaft bearings, then drains down through the vertical camshaft-drive assembly into the sump. It does not reach the pump until it passes through a screen. One side of the pump passes the oil from the reservoir to the engine, and the other side pumps the oil from the sump of the engine to the reservoir. Care must be taken to see that all gaskets have the required amount of holes, not only those that are used to pass the bolts through, but also the ones permitting the oil to pass from one section to the other. These passages must be clear.

The water pump is located on the front end of the engine, and has a gear-driven impeller. The water inlet is located in the center of the pump housing. The pump has two outlets, one on top and one at the bottom, so that the water is equally divided to each bank of cylinders. Each bank has an individual water manifold which has an outlet to each cylinder. The cylinder is connected to the manifold by a rubber hose connection that should be taped and shellacked. The water passes into the cylinder in a tangential direction and passes around the cylinder leaving at the top. If the pump must be repacked, it is necessary to remove it. The gears should not have excessive backlash.

The carburetor must be carefully inspected. The floats are inspected by removing the chamber cover. Floats in the Zenith carburetor are made of sheet copper, spun, and the upper part sweated in place. The float should be tested for tightness by submerging it in water. In replacing the float it should balance freely and not rub on the sides of the float chamber.

The float needle valve should seat properly. If it is found by filling the chamber with fuel that the fuel flows out of the fuel inlet, the needle valve should be ground in with the use of a fine abrasive. In grinding, hold the needle upright.

All fuel strainers must be clean. In a new carburetor, scales often form due to oxidization. Impurities may clog the strainers and cause poor carburetion, making the engine miss and backfire. Broken strainers

are almost impossible to repair and should be replaced with new ones. It is unnecessary to remove the carburetor from the engine to clean or replace strainers.

The main and compensator jets should be examined and cleaned without removing the carburetor. Both sets of jets must be the same size. Main jets are No. 145; compensator jets, 155. These are cleansed with gasoline and blown out with compressed air. Wires should not be used except in severe cases of clogging.

Disconnect the throttle controls at the carburetors, and open the control intil it stops. The butterflies are now wide open. Move the hand control and see if the rod meets the carburetor control; if so, retard the hand and carburetor controls and see if they both travel from full retard to full advance on the hand-control quadrant. Check the Y-connections in the same manner. If correct, they are secured, with throttling adjustment left loose for further adjustment. The throttling-adjustment screws on the carburetor should be turned to the left until the butterflies in the carburetor are closed. These are held in the closed position and the rod connecting the carburetor and control is then adjusted.

In operating a Liberty engine without an oil reservoir, it is necessary to connect the outlet pipe of the pump to the inlet pipe, filling the sump with 4 gal. of lubricating oil. It is much better to have a reservoir as this helps to keep the oil cool. In this engine the best operating temperature is about 120° F.; this is important, because cold oil will not furnish proper lubrication, and, if the engine runs warmer, the oil film may be broken.

The water outlet temperature should not be allowed to rise above 170° F. The water pump should discharge 100 gal. per min. at 1,650 r.p.m. To determine the direction of rotation of an engine refer to any one cylinder as No. 1L, and slowly rotate the crank in either direction. Keep in mind that the inlet valve opens immediately after the exhaust closes. Therefore if the direction in which the crank is being rotated causes the inlet valve to open immediately after the exhaust closes, the crank is being rotated in its normal direction. If the valves do not operate in the above order, the crank is being rotated counter to its normal direction of rotation.

To determine the firing order of the Liberty engine, check by the exhaust valve method as is done in common practice on any engine. With No. 1L cylinder on the firing stroke, turn the crankshaft in the direction of rotation about 170 degrees and note the next exhaust valve that opens on the right bank. Continue with this procedure until all cylinders are checked.

Approximate top center can be found with the depth gage, without the use of the degree plate, in the following manner: Remove the spark plugs from No. 1 cylinder of the left bank and No. 6 cylinder of the right

bank and put a depth gage in each one. Turn the crankshaft so that No. 1L piston is about 1 in. from the top and mark both depth gages. Turn the crankshaft in the direction of rotation, until the mark on the gages in the cylinders has traveled up and over top center and is down again to where it was first marked. Now mark the depth gage in No. 6R cylinder which will be some distance below the first mark. Space these two marks exactly in the center by dividing the distance between the two. Rotate the crankshaft in the opposite direction until the center mark is reached, then mark the gage in No. 1L cylinder. Rock the crankshaft back and forth and notice the rise and fall of gage in No. 4L cylinder. It should be on top center. Due to the piston speed variation through different parts of the stroke the above top center will not be absolutely T.D.C. but will be within ¾ degree.

Another way to find top center with the use of a depth gage is as follows: A depth gage is placed in No. 1L-cylinder and the piston is brought to within 1 in. from top center. A scriber or scratch awl is used to make a mark on the periphery of the propeller hub with respect to the crankcase center-line. Now rotate the crankshaft in the direction of rotation until the depth gage travels up and back to its former position. Another mark is made on the propeller hub with the same relation to the crankcase as before. Divide the distance between the two marks into halves and line up the point thus obtained with the mark on the crankcase by rotating the engine in the opposite direction. This method can be used by marking at the end of the club or propeller.

To find top center with a degree plate it is necessary only to remove the propeller or club. The degree plate is fastened to the inner hub flange. A pointer is clamped on the crankcase and the depth gage inserted in No. 6L-cylinder. Rotate the crankshaft until the depth gage is about ½ in. from the top center, marking the gage at this point. Continue to rotate the engine until the depth gage ceases to rise, the piston then being approximately on top center. Rotate the crankshaft until the depth gage has moved down so that the mark is on a level with the edge of the spark-plug hole. Now mark the degree plate where the pointer is indicating.

With a pair of dividers find a point midway between the two marks on the disk. This point will indicate the exact top center of No. 1L-cylinder and No. 6R-cylinder. Rotate the crankshaft until the bisecting mark is in alignment with the pointer. With the crankshaft in this position, move the disk so that the mark T.D.C.-1L, which is stamped on the disk, is in line with the pointer, then clamp permanently in this position.

The valve clearances should be checked only when the piston is on top center of the firing stroke. In checking valve clearances in two revolutions of the crankshaft, it is necessary to follow the firing order of the

engine. The firing position of No. 1L-cylinder is the neutral position on the exhaust stroke of No. 6L-cylinder. Starting with No. 1L-cylinder at the firing position, check the valve clearance of both valves, then No. 6R-cylinder, which is the next in firing order, and rotate the crankshaft 45 degrees at which time No. 6R- will be on its firing point. Having checked No. 6R, rotate the crankshaft 75 degrees and check No. 5L, and by rotating the crankshaft 45 degrees, No. 2R-valves are ready to be checked. It will be noticed that the sum of the numbers of these pairs of cylinders is always seven.

To set the valve clearances on the Liberty engine remove the cotter pin in the valve-tappet screw. The nut is loosened to allow the screw to be forced down enough to permit the removal or replacement of the shims between the tappet-screw heads and rocker arm. The valve springs must be compressed while performing this operation. A piece of flat stock may be placed between the rocker arm and valve-spring retainer cup and turned on its side, thus pressing the valve assembly down. The intake valve clearance should be set .014 to .016 in. and exhaust valve .019 to .021 in.

The use of the degree plate or disk in checking valve clearance is not only the most practical, but the most accurate method. Having once set the disk for one bank of cylinders, it is not necessary to change the disk setting. Rotating the crankshaft 45 degrees from the firing position, No. 1L-cylinder will put No. 6R-cylinder on the firing position. By moving the crankshaft to 130 degrees past to center, No. 6R-exhaust should open. Always check by the opening of the exhaust and closing of the intake valves.

All spark plugs must be kept clean. Porcelains must not be cracked or broken. The gap in plugs between the electrodes should be .015 in. to .017 in.

Remove the distributor, which is made of bakelite, by releasing the four spring clips and two retainer screws. Having loosened the cover, care must be taken that the carbon brushes are not broken. Examine the inside of the distributor to insure that the segments have not become dislodged or fouled with carbon. Segments and brushes must be kept free from grit and scratches.

Next examine the parallel breakers when the rubbing blocks are on the highest point of the cam. The points must not be burned or pitted. If burned, they must be cleaned with crocus cloth. Fold the cloth so that both points will be cleaned when it is drawn between them. Main breakers should open .012 in., auxiliary breaker .014 in., when on the highest point of the cam.

Ground wires must have clean terminals to insure proper contact. Wires must be kept clean and free from oil and other foreign matter.

The breakers should open 30 degrees before top center when the con-

trol lever is in the fully advanced position. Set the crankshaft 30 degrees B.T.C., and, using a set of test lamps, note that the lights go out when the crank is 30 degrees B.T.C.

With the control in the retard position, the breaker should open 10 degrees P.T.C. After the first operation, retard the lever and rotate the crankshaft until the lamps go out. If this is at the 10 degrees P.T.C., the engine breakers are opening at the proper time. Another method is to place cigarette papers between the two points and see if the papers are released at the same time.

To check the wiring, start No. 1L-cylinder and check each wire. All wires leading from the right distributor are attached to the front spark plugs of each cylinder. All rear spark-plug wires are attached to the left distributor. Checking high-tension leads can be done in two revolutions of the crankshaft while the valve clearances are being checked. The leads must be rigid and the terminals properly fastened. The insulation must not be punctured or broken. Tape all parts that are chafed. The terminals can be pulled with a light stress to see that they are tight and not hanging by just a few strands. Spark-plug terminals should snap on the spark plug.

In testing high-tension leads, use an electric bell or buzzer outfit, hooking one wire to the distributor end and the other wire to the spark-plug end. If on the right lead, a circuit is formed and the bell will ring.

282. Operation. Having noted all defects, all necessary changes made in assembly, parts repaired and adjusted, the engine is made ready for starting.

Care must be taken to see that the proper amount of fuel, oil and water are in their respective tanks. The oil sump must be filled with at least 4 gal. of oil if no tank is used. Turn on the fuel and water to see that they flow freely.

Inspect the club or propeller bolts to see that all are secured and cotter-keyed. If mounted in an encasement, see that the bars or doors are properly placed or locked.

Flood the carburetor. In cold weather it may be necessary to prime the engine. This is done through the petcocks on the intake manifold. Rotate the crankshaft one or two revolutions to draw a charge into the cylinders. Stand clear of the propeller, retard the spark control and throw in the switch, opening the throttle just enough to keep the engine running when it starts.

The gear ratio of the Liberty engine is 12 to 1. This means that for one revolution of the crankshaft it is necessary to turn the handcrank 12 times. This eases the usual practice of heavy pull on the engine and makes it easy to start the engine.

After starting the engine the spark is gradually advanced since retarded spark causes excessive heating. Both switches should now be in

the running position which will cause the engine to function on double ignition. The engine should be run at an idling speed of about 750 to 800 r.p.m. During this time the engine is taking its current from the generator. In running at a lower speed, the engine will draw current from the battery. Water and oil should be allowed to warm properly, care being taken not to allow the temperature to rise too high. The oil pressure may increase when the engine is cold, but as soon as the oil becomes warm and thin, the pressure will drop. At idling speed the oil gage should not show more than 5 to 7 lb. per sq. in., at full speed 23 lb. to 30 lb. per sq. in. Water temperature should not rise above 170° F. While the engine is still idling, it is necessary to make a careful examination for leaks, breaks and other minor details that need attention before accelerating the engine.

Inspect the engine to see that all plugs are operating. Cut out one switch at a time, and note any plugs "missing." Both carburetor butterflies must be synchronized. The exhaust flame is a good indication of the mixture quality in the respective cylinders. If the mixture is correct and the engine is operating properly, a 10-min. run may be made to check for any further engine troubles. This run is made at wide-open throttle. Watch all gages and tachometer to see if any changes occur during the run.

The engine should be stopped and the valve clearances checked, comparing them with the clearances taken when the engine was cold. All defects must be noted and necessary changes made. The engine must then be thoroughly cleaned and wiped. No waste or rags should be left around the various parts of the engine. Shut off all fuel, oil and water supply lines after completing the test. All grounds must be closed and current shut off.

Practical Work on Hispano-Suiza Engine

283. Detail Inspection. Make a thorough inspection of all exterior bolts, capscrews, and units, using a wrench, and, if any of them are found to be loose, they must be tightened. Replace all bolts, capscrews, studs and nuts that are missing or have been stripped. In cases where female threads are stripped in castings or other parts, the hole must be redrilled and tapped, using the next larger size drill and tap. A new stud must be made to fit the new thread. All broken or sheared-off cotter pins must be replaced.

Fill the fuel tank with a good grade of gasoline. Gasoline should be strained through a chamois skin placed over the funnel to collect any water or other impurities. Be sure that the funnel is held firmly against the tank. When gasoline comes in contact with the chamois, static electricity is generated, which may cause a spark unless the funnel

is grounded. This often occurs in warm weather, when high Baumé test gasoline is used. The line must be washed out by turning on the cut-off cock under the tank, allowing the gasoline to flow out; or use air, forcing it through the line to blow out any obstructions that might clog the system.

Inspect the gasoline strainers for any punctures or collected sediment which may obstruct the fuel flow. Inspect all lines for leaks, kinks or broken connections. Be sure the carburetor-float chamber fills properly and that the carburetor does not flood. Have plenty of oil in the lubricating tank.

Make sure that the oil level in the crankcase is as required. This can be determined by gage plugs placed for this purpose in the right-hand side of the lower half of the crankcase. The normal level corresponds with the height of the second plug, giving about 2.64 gal. or 10 liters in the crankcase. It should never be filled above this plug, as the oil will be splashed and carried to the plugs, causing the spark plugs to foul. See that all oil lines are free from obstructions and that the connections are in good condition.

Fill the radiator or tank, and, if there are any cut-off valves in the circulating system, see that they are wide open to allow a free passage for the circulating water. Use water that is as free from lime and other impurities as possible. Should there be an air pocket in the line, open the air-vent cock which should be provided at this point. Let this vent cock remain open until all air has escaped and the water starts to flow. Examine the radiator, pump, water jackets, piping and all connections for leaks.

Examine the lines for leaks and sediment, and if they are not clean do not let the water pass through the engine. Also examine all water hose and hose-clamps. If necessary replace them with new parts. All pipe connections must be tight. Pipe joints or connections should be of the proper size, fit correctly, and be soldered.

Examine the carburetor float for punctures and leaks. Examine the float-valve and seat to see that they are both in good condition, and that the float-valve fits in the seat and does not leak.

Examine the strainer for punctures which might allow dirt to be carried into the float-valve, causing the flooding and plugging of the jets. If the strainer is fouled it is necessary to clean it thoroughly.

Examine the jets and compensators to see that they are clean and properly tightened. It is good practice to use compressed air to clean the parts.

Inspect the butterfly valves for full opening and closing. Determine the quality and quantity of the fuel, oil and water. Note the quantity of gasoline in the tank, and if the fuel has been standing exposed to the air. This causes the lighter hydrocarbon gases to evaporate, leaving

very low Baumé test gasoline. This can be determined by smelling or pouring a small amount into the hand and noting the time it takes to vaporize.

Note condition and amount of oil. If the oil is black and dirty, it should be drained off and replaced with clean oil. Note the amount and condition of the water in the radiator. If the water appears muddy or rusty, drain and flush the radiator until the water runs out clear. Then fill it with clean water. It may be necessary to boil out the radiator, by using soda ash.

Determine the Direction of Rotation by Observing the Order of Opening and Closing of the Inlet and Exhaust Valves. Remove a spark plug from each cylinder to relieve the compression. Then simply notice which are the inlet and which are the exhaust valves. Try turning the crankshaft in both directions, watching the valve action of any one cylinder. The direction of rotation of the crankshaft that causes an exhaust valve to close and an inlet valve to immediately begin to open on any one cylinder is the correct direction of rotation for that engine. The piston in that cylinder will be just a little past top center. It will have just completed exhaust stroke and will have begun suction stroke.

To Determine Direction of Rotation from Magneto. Most manufacturers stamp an arrow on an oil-hole cap of their magnetos, indicating its direction of rotation. Trace the gearing to prove the engine rotation from this arrow. If this does not check up with the valve action, the magneto has had its rotation reversed. Take off the distributor and note the gear meshing. Some magnetos have two marks on the distributor gear, one marked *A*, which means anti-clockwise, the other *C*, which means clockwise. A magneto, the rotor of which turns in the direction of a clock's hands, *from the gear end*, is a clockwise magneto, and is so indicated by the arrow on the oil-hole cover. To have this magneto remain so, the distributor gear should mesh at the tooth marked *C*. If this is not the case, find the direction of engine rotation by tracing the gearing just opposite to the arrow on the oil-hole cover. If there is no arrow on the oil-cup cover, another method of determining the direction of rotation is to watch the cam operate the breaker. If rotating in the correct direction, the cam will strike the breaker bumper on the side nearest its fulcrum, traveling from the fulcrum. In some magnetos, where the distributor gear is not marked, it is necessary to check the breaker openings with engine-firing positions, both advanced and retarded.

The contact-breaker arm should be actuated from only one direction. Any magneto, can run backward without doing any serious damage to its parts, and frequently does when preignition occurs.

Pitch of Propeller. The purpose of the propeller is to pull or push the plane through the air. The force it generates is termed the *thrust.*

The principle of the propeller on an airplane is similar to the principle of a screw propeller on a motor boat, but differs in construction. The shape of the propeller will readily indicate the direction the engine is to be run, as the propeller always screws into the air, whether of the tractor or pusher type. Furthermore, the trailing edge, or rear edge, is always the thin edge. Unless a propeller has been incorrectly installed, it is quite easy to see in which direction it should rotate. The direction of the propeller will be in such a direction that the flat side of the blade will engage the air and press against it.

If the engine is equipped with an air or electric starter, turn on the source of power and note the direction of rotation of the crankshaft. If a hand-starting crank is used, the direction can readily be seen by inserting the crank handle and noting the direction in which the crank engages with the crankshaft attachment or mechanism.

To determine the firing order of an engine by piston position and the opening and closing of the intake and exhaust valves, rotate the crankshaft until piston No. 1L is coming up with both intake and exhaust valves of that cylinder closed. On this stroke of the piston, this charge will fire when the piston reaches top center. This cylinder is No. 1L of the firing order. The next cylinder to fire will be on the right bank. The next piston coming up with both valves closed will be the next to fire. It is No. 4R. Continue this operation during two complete revolutions of the crankshaft.

To check valve clearances, rotate the crankshaft until the piston is on top center of the compression stroke. In this position both valves are closed, and the mechanic can be sure that the setting will be made in the lowest part of the cam.

Check valve clearances in two revolutions of the crankshaft. Set piston No. 1L on top center of compression stroke and check valve clearances. Following the firing order of the engine, continue in this manner until each cylinder has been checked with piston on top center of compression stroke. On this engine the valve clearances are adjusted to .078 in. or 2 mm.

Check time of opening and closing of intake and exhaust valves by piston position and depth gage. Due to the location of the spark-plug holes in the side of the cylinder block, it is impossible to use a depth gage accurately to determine the time of closing of the intake and opening of the exhaust valves.

To set the degree plate or disk, first determine T.D.C. as follows: Remove one spark plug from each cylinder to relieve compression, allowing the crankshaft to be turned freely by hand. Remove the inside spark plug and put the indicator in this hole, No. 1L. Remove the propeller, leaving the hub intact, and place the degree plate temporarily on the inner hub flange. Rotate the crankshaft clockwise until the

piston in No. 1L is on the compression stroke and is shown by the indicator to be approaching top center. When the piston is within ¼ in. to ½ in. of top center, note the reading shown by the indicator.

Clamp the degree-plate pointer to some convenient part of the engine. In ordinary practice it is secured under the cylinder hold-down nut and extended over the degree plate. Note the position of the degree plate and pointer, and make a mark on the degree plate at the point indicated by the pointer. Continue to rotate the crankshaft in the same direction until the piston has passed top center and is starting down on the explosion stroke. Stop the crankshaft when the position of the piston is the same as when coming up on the compression stroke. This is shown by the indicator reading. At this position mark the degree plate a second time at the pointer. Mark a point equidistant between the two points and rotate the crankshaft counter-clockwise until the middle mark passes the pointer about 1 in. In going past this mark, all backlash of gears is taken up. Now rotate the crankshaft in the direction of rotation until the middle mark comes directly under the pointer. Loosen the degree plate and set the top-center mark directly and securely under the pointer. Care must be taken that the crankshaft is not moved. The piston position for No. 1L- and No. 4L-cylinders is T.D.C.

To check the timing of the valves, rotate the engine counter-clockwise to allow sufficient clearance to place a cigarette paper between the intake and exhaust cams and their respective tappets. Then slowly rotate the crankshaft in a clockwise direction, feeling the paper under the exhaust cam. The paper should come free at 32 mm. or 10 degrees P.T.C. proving that the exhaust has closed at the proper time. At the same time the paper under the intake cam should begin to tighten, proving that the intake valve is starting to open.

If the paper under the exhaust cam comes free when the crankshaft is 15 mm. or 4.7 degrees P.T.C., the valve closes early. If it does not release until the crankshaft is 50 mm. or 15.9 degrees P.T.C., the valve closes late. This test applies to both intake and exhaust valves.

If the timing is early or late 2 degrees or more on crankshaft timing, it will be necessary to change the setting of the camshaft in order to get the timing more accurate.

Check up the spark gap. The magneto will always operate best with a spark gap of .020 in.

Examine the magneto carefully. Remove the distributor block and inspect inside for carbon dirt that may be in the rotor path or on the segments. Wipe it with a clean soft cloth. Be careful in replacing the block that the carbons are not broken.

Check up the breaker gap. The maximum distance between the points should not exceed .020 in. or 5 mm. The breaker points must open the correct distance. Any change in the adjustment of the breaker

will cause the break to occur with the armature a different distance from the pole pieces and may effect the working of the magneto. If points are burned, clean them up with an oil stone and adjust to proper clearance.

Be sure that the ground-wire connections are good at the ground-wire switch, magneto-ground terminal and ground on the engine.

To determine the degree of advance of an engine, set the degree plate on T.D.C. of compression on No. 1L-cylinder. Rotate the crankshaft backward far enough to allow the breaker points to close. Then rotate the crankshaft slowly in the direction of rotation until a cigarette paper placed between the points is released enough to draw out with a slight pull. Note the position of the line mark $M.A.-1$ and $4L$ on the plate with respect to zero.

If the paper does not release with the line directly at the pointer, adjust the magneto coupling until the paper barely releases at this position of the crankshaft. Synchronize magnetos by means of a thin cigarette paper.

Check the wiring from the spark plugs to the distributor block. Check the wires from the distributor block and be sure they are placed in relation to the firing order of engine which is 1L, 4R, 2L, 3R, 4L, 1R, 3L, 2R.

Examine the wires for any broken insulation and be sure they are protected from all grounds. Examine all terminals and see that they are properly soldered to the high-tension leads. Test with a buzzer all wires from the segment in the distributor block to the proper cylinder.

After making note of each defect, make corrections according to the standard log.

284. Operation. There is no spark retard or advance on the Hispano-Suiza engine. Ignition is furnished by two Dixie 800 magnetos, set to fire 20 degrees B.T.C.

Turn on the fuel and water and see that the float chamber fills with gasoline. For starting the engine the throttle lever should never be opened more than $\frac{3}{16}$ in. from the stop screw. Prime the engine by injecting a small quantity of gasoline through the four petcocks on the intake manifold, and start it by means of a hand-starting crank, geared to a small starting magneto which gives a hot spark at low-engine speeds for starting. The starting crank is geared to the crankshaft by reduction gearing, to facilitate easy starting and cranking.

As soon as the engine is started, leave the throttle in the starting position so that the engine runs at about 800 r.p.m. in order to warm up. See that the water and oil are circulating properly. Note the oil presure, which should be from 40 to 50 lb. with an oil temperature of 150° F. at an engine speed of 1,450 r.p.m.

Note the temperature of the water. The desirable temperature of the outlet water is about 180° F., and the inlet about 150° F.

Note any oil or water leaks. Stop the engine by allowing it to run at the idling speed before the switch is pulled and it is stopped. Check and adjust the valve clearances while the engine is hot. Note the difference between hot and cold valve clearance.

Repair any leaks that may occur. Make all necessary adjustments and remedy all faults until the engine operates properly.

Start the engine and let it run at idling speed until it is thoroughly warmed, then run the engine at full speed for 10 min.

Note the temperature of cooling water. Never allow the water to rise over 180° F.

Note the temperature of the lubricating oil. The temperature of the oil should be held, even in the warmest weather, below 93° C. (200° F.) under all conditions, and is best not to exceed 70° C. (160° F). Note pressure of lubricating oil and inspect all gages.

Practical Work on Curtiss OXX-6 Engine

285. Detail Inspection. All nuts and bolts must be examined to determine tightness and freedom from defects. Care should be taken that the threads are good. The absence of nuts and bolts must be carefully searched for and replaced where missing. Cotter pins must be in their places and properly spread. Proper castellation of nuts, sheared cotter pins and cracked nuts or washers must be looked for and the necessary corrections made. Fuel lines must be carefully inspected to insure free flowing of the fuel from the tank to the carburetor, avoiding unnecessary bends and kinks. Care should be taken to avoid leaky or loose fuel connectors.

The water system consists of a water pump, radiator and necessary fittings. Water is received from the radiator or tank by a rotary pump located at the gear-end of the engine. It is forced through a manifold, which has a connection to each cylinder near the base of the water jacket. It rises in the cylinder jacket and is forced out through a pipe, through the valve rocker fulcrums and back to the radiator. Inspect for leaks and places where the water may be pocketed. Kinks often cause this condition.

The oiling system must be carefully examined for leaks, bent or broken pipes and loose or defective connections. The oil for the lubrication of this engine is contained in the sump. The oil gage will indicate the proper amount of oil to pour into the sump. This is usually about 3 gal. The oil pump is located in the rear of the sump and is of the gear type, being driven from the crankshaft. All connections must be well

fitted and, if necessitated by vibration, soldered. The best test is to blow out all lines with air.

Inspect the carburetor, making certain that the float chamber is clean and that the float does not leak. See that the float-valve works freely, seats properly and is perfectly straight. See that the strainers are in their proper places, free from holes or breaks and contain no sediment. Examine the jets for cleanliness. They must be in their proper places, screwed up tightly, and of the proper size. Clean out the carburetor with compressed air before assembling. Calibrate the throttle control to see that it travels its full range. See that the butterfly valves open and close easily and properly. Examine the quality and quantity of fuel, oil and water. The fuel must be of the proper specific gravity, which is determined by a hydrometer test. If the fuel has been standing for some length of time, do not use it, but replace it with fresh fuel. The oil must be clear and free from carbon sediment. It should not be too light, and should have the proper viscosity.

Do not allow muddy or rusty water to be circulated through the engine. The radiator must be kept full.

Rotate the engine in either direction. Its direction of rotation may be determined by noting the order of opening of the valves of any cylinder. The closing of the exhaust valve, and the opening of the intake valve are the proper events by which to determine the direction of rotation.

The magneto will not produce a proper spark when rotated counterclockwise; therefore, trace the direction of rotation from the magneto to the crankshaft. If the magneto is retarded, the breakers just open when the piston is on T.D.C. of the compression stroke, and the magneto rotor has been turning in the direction of the arrow on the oil-hole cap, the direction of rotation is correct. See that the breaker-actuating cam travels in such a manner as to always have the top of the cam moving away from the arm instead of striking against it.

The pitch of the propeller indicates the direction of rotation of the engine, if the propeller is installed on the right machine. A section through the propeller shows a flat and a curved side. The flat side, being the side when the actual thrust takes place, always leads so a glance at the propeller will tell the direction of rotation. Engine rotation can also be ascertained from the water pump. The water inlet pipe is found and the circulation traced through the pump to the cylinder outlet. By tracing these connections and the drive of the water pump, the direction of rotation can easily be determined. To find the direction of rotation from the starter, note the direction in which the starter engages. This is the direction of rotation.

The firing order of an engine is easily determined by noting the order of operation of the valves. It is customary to start with No. 1L-cylinder

and to determine the order of opening of the inlet valves, although it is possible to refer to their closing or the opening or closing of the exhaust valves. As the crankshaft is slowly rotated in its normal direction, note when No. 1L-inlet opens, what inlet opens next, and so on until all the cylinders have been checked.

The proper place to check valve clearances is at T.D.C. of the compression stroke of each cylinder. This insures against the rocker arm riding on the cam flank. To check clearances in two revolutions of the engine, rotate the crankshaft until No. 1 piston is at T.D.C. of the compression stroke. Check through the entire eight cylinders, following the compression stroke sequence throughout. All valves should have .010 in. clearance.

The depth gage method of valve action is as follows:

Inlet opens = $\frac{3}{64}$ to $\frac{7}{32}$ P.T.C. = 0.0468″ to 0.0937″.
Inlet closes = $4\frac{35}{64}$ to $4\frac{5}{8}$ P.B.C. = 4.546″ to 4.625″.
Exhaust opens = $4\frac{5}{16}$ to $4\frac{27}{64}$ B.B.C. = 4.312″ to 4.421″.
Exhaust closes = $\frac{1}{64}$ to $\frac{3}{64}$ P.T.C. = 0.015″ to 0.046″.

By degree plate

Inlet opens 10° to 16° P.T.C.
Inlet closes 38° to 42° P.B.C.
Exhaust opens 46° to 50° B.B.C.
Exhaust closes 6° to 10° P.T.C.

Check the spark-plug gap, which should be from .015 in. to .017 in. and must be corrected if otherwise. Examine the magneto to see that the rotor brush is on the proper segment when the contact points break. The brushes and the path in the distributor block must be clean. The brush springs must have the proper tension. The high-tension leads must be on their proper terminals according to firing order. The breaker gap must be checked and set for .020 in. clearance. The points must be clean and secure. See that the ground wires are secure, free from oil, and that the insulation is intact.

Attach the degree plate, set the magneto at full advance, and with a cigarette paper between the breaker points, rotate the crankshaft until the breaker points open enough to release the paper. Note the amount of advance as indicated by the degree plate. The retard is found in the same manner.

To synchronize magnetos by the cigarette paper method, place the paper in both breakers. If one breaker opens later than the other, change the one that has the least advance to correspond with the other. If synchronizing lamps are used, the primary connection from the stationary breaker-point holder must be removed. Then wire up as in Fig. 519.

Inspect Wiring. The firing order of the Curtiss OXX-6 engine is 1,2,3,4,7,8,5,6. See that the wires from the segment to the spark plugs are as follows.

TABLE XLVI.—CURTISS OXX-6 FIRING ORDER

Segment No. 1	to	Cylinder No. 1
Segment No. 2	to	Cylinder No. 2
Segment No. 3	to	Cylinder No. 3
Segment No. 4	to	Cylinder No. 4
Segment No. 5	to	Cylinder No. 7
Segment No. 6	to	Cylinder No. 8
Segment No. 7	to	Cylinder No. 5
Segment No. 8	to	Cylinder No. 6

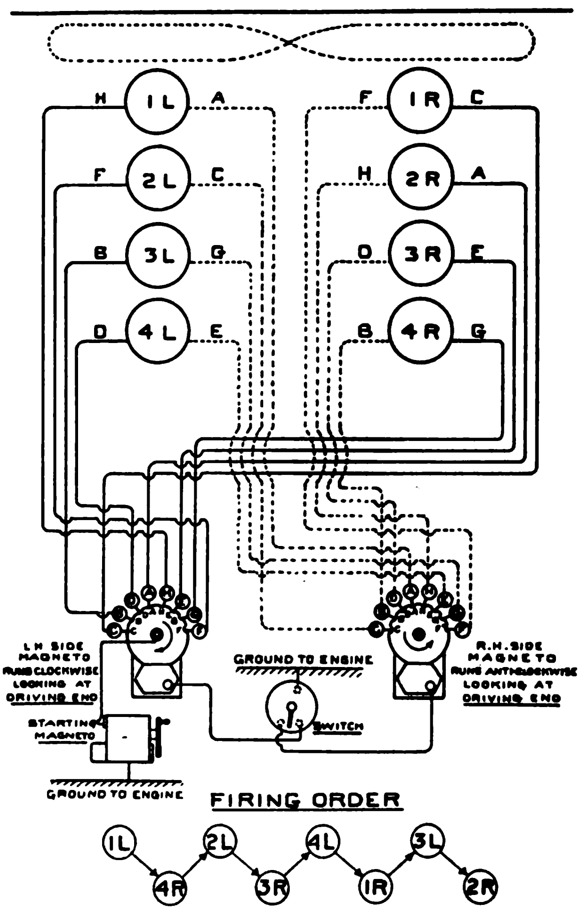

FIG. 519.—Wiring diagram.

Examine all wires for burned insulation and broken strands. The terminals must be clean and secure. No loose wires should be left around the engine as they may cause serious trouble. Wires should be tested with buzzers. All defects must be tagged and, when necessary, corrections should be made immediately.

286. Operation. Start the engine with the spark retarded; turn on the fuel and prime the carburetor; if necessary, prime the engine. "Crack" the throttle. The ground switch should be opened and the engine started with the means at hand. Idle the engine until it is thoroughly warm. See that oil and water circulate freely. Note the oil pressure. The water inlet should be at 150° F. and the outlet at not more than 180° F. Examine all the parts that have been adjusted or repaired.

Stop the engine and check over the valve clearances, adjusting them while the engine is still hot. Make all necessary changes so that the engine operates properly.

Operate the engine slowly until it is warmed again. Operate it at full speed for 10 min. Note the water and oil temperature. The water should register 180° F. and the oil 120° F. Make the oil pressure 40 to 60 lb. Inspect all gages for proper working and proper connections.

PERFORMANCE TEST OF HISPANO-SUIZA (150 Hp.) AIRCRAFT ENGINE

287. Run with Low-Baumé Gasoline. *Preparation for Run.* Perhaps the most practical device for making accurate horsepower tests and determining the actual performance of an aircraft engine is the *electric dynamometer*. The field frame, instead of being rigidly bolted to the base or cast integral therewith, is supported in two large radial ball bearings on pedestals rising from a cast-iron base. The armature shaft is connected through a flexible coupling to the shaft of the engine to be tested. The complete installation comprises a large cast-iron base, with adjustable standards to take engines of all sizes, an electric cradle dynamometer and a switchboard. A sketch of such a dynamometer is shown in Fig. 520.

When the armature is rotated by the aircraft engine it exerts a turning effort on the field frame, A, and tends to carry the latter around with it. Two radial arms extend from the field frame, B, for measuring the pull exerted by means of the scale, C, and the other, D, for balancing the former. Current is induced in the armature of the generator, the same as in the ordinary dynamo, and may be used in lighting a bank of incandescent lamps, or it may be dissipated in a water rheostat or in the main trunk line. The force exerted by the lever arm, B, on the scale, C, is equivalent not only to the electromagnetic reaction, but to the armature bearing friction and the commutator brush friction. The only item not included in this force is the friction in the ball bearings supporting the field frame, which is negligible. The method used in connection with the dynamometer for determining the brake horsepower derives the formula:

$$\text{B.hp.} = \frac{2}{33{,}000} \times \text{r.p.m.} \times W$$

As in the case of all other dynamometers, torque and speed measurements must be made simultaneously, and for this reason a tachometer is mounted on top of the dynamometer. The dynamo is also capable of operating as a motor, and by means of a starting rheostat on the switchboard it can be used to start the engine.

The engine is connected in the usual manner with the necessary accessories such as fuel tank, platform scale, oil pressure gage, and a cooling water tank with a thermometer in the inlet and outlet, as described in previous paragraphs. In this performance test commercial or low-Baumé gasoline, 62 to 68° Bé., is used as this is the fuel that is generally obtainable at an air station. Before starting the test make a thorough examination and inspection of the engine as outlined under "Detail

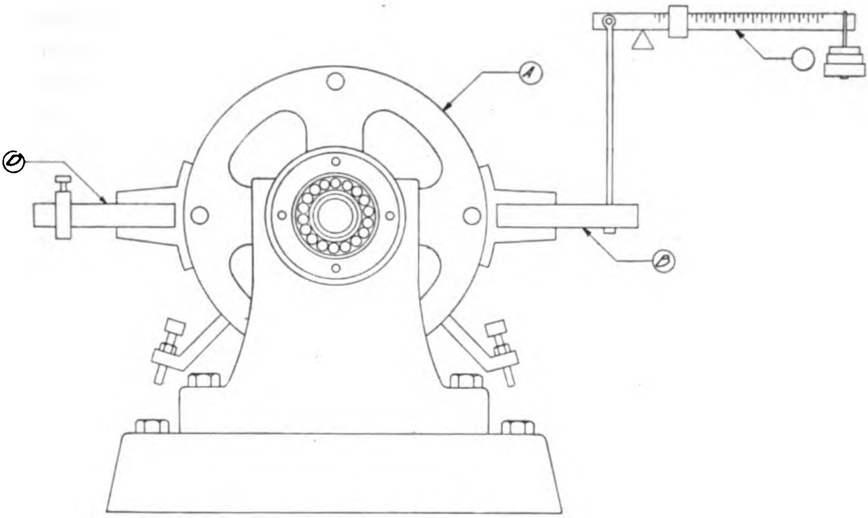

FIG. 520.—Cradle dynamometer.

Inspection." Also make a thorough inspection of all accessories such as the dynamometer and switchboard, together with all instruments.

When the inspection has been completed operate and warm the engine as outlined under "Operation" with the following exceptions: In starting, use the dynamo as a motor by means of the starting rheostat. Then, by cutting out resistance, slowly speed the engine up to 400 or 600 r.p.m. With the spark fully retarded, gradually open the throttle until the engine operates under its own power and picks up the load. Then, by means of the starting rheostat, convert the motor into a generator and proceed to operate. In this warming-up operation the inlet and outlet cooling water must be watched closely so as not to allow the temperature of the inlet to rise over 150° F. nor that of the outlet to exceed 180° F.

When everything is in readiness, upon completion of the preliminary warming-up operation, proceed with the test and run with low-Baumé gasoline as follows:

Speed vs. Brake Horsepower and Fuel Consumption. This *test run* as performed, consists in running the Hispano-Suiza engine at variable speeds from 600 to 1400 r.p.m., using low-Baumé gasoline, with the throttle wide open and the spark fully advanced. The speed is controlled by means of a dynamometer. The object of the test is to show the effect of speed upon brake horsepower and fuel consumption.

During the warming-up process, as heretofore described, the instructor in charge will assign the men in the squad to their various stations and duties for the purpose of operating, observing and taking data. One man is assigned to noting and recording the time; one, to the tachometer; one, to the brake; one, to the scale for recording the weight of fuel; one, to read the temperature of the cooling water, outlet and inlet; one, to the throttle and switches; and one man to act as yeoman who will collect and record all of the data obtained from the test. This yeoman will make out a log similar to the one shown in Fig. 521, and he will record in this log all of the data as it is obtained or as fast as the readings are taken with the exception of the brake-horsepower column. The brake horsepower must be computed by each man individually, so that he will be familiar with the formulae.

The time allotted for each run is 10 min. or more. This time will depend entirely upon the length of time allowed for the experiment. The longer the time allowed for each run, the more accurate the results will be. Readings should be taken every 2 min. for a total of 10 min. for each run and the average of these readings for the length of each run, will be recorded in the log by the yeoman. The timekeeper takes an important part in this as in all other experiments and he must pay strict attention to his duties at all times. As soon as the instructor has carefully inspected everything and has seen to it that every man is in his respective position and understands exactly what is required of him, he will instruct the timekeeper to proceed with the experiment.

It is now up to the man keeping time to instruct the men when to take readings. About 10 sec. before the 2 min. are up, the timekeeper will tell the men to get ready. This gives each man ample time to prepare himself and will enable him to take more accurate readings. It is very important that each man should thoroughly understand just what is required of him and he must at all times take these readings as accurately as possible, otherwise the experiment will not be of any special benefit to him, and the results, when plotted in a curve, will not bring out the proper conclusion.

When the instructor in charge is satisfied that the engine is working properly and the temperature of the cooling water at the outlet has

reached 180° F. and that of the oil, 120° F., proceed with the test run.

With wide-open throttle and spark fully advanced, cut in resistance, by means of the rheostat, until the speed of the engine is reduced to 600 r.p.m. As soon as the timekeeper gives the starting signal, readings are taken every 2 min. for 10 min., as heretofore stated.

When the last reading has been taken with the speed at 600 r.p.m., the instructor will cut out the resistance until the speed of the engine has increased to 800 r.p.m. The squad proceeds as before, taking readings every 2 min. for 10 min.

In the same manner as heretofore described, the speed is increased to 1400 r.p.m., in steps of 200 r.p.m. each, and readings taken for each successive increase in speed.

The brake horsepower and the hourly consumption of fuel cannot be recorded at the time of taking the data, as they have to be computed.

From the readings recorded in the log, the following are computed. The weight of fuel used per hour is found by multiplying the weight consumed for 10 min. by 6 and the weight of fuel per brake horsepower per hour is found by dividing the total weight of fuel per hour by the brake horsepower computed for that run.

Brake horsepower should be computed as follows:

$$\text{B.hp.} = K \times \text{r.p.m.} \times W$$

where,

$$\text{B.hp.} = \text{brake horsepower.}$$
$$K = \text{constant.}$$
$$L = \text{length of brake arm in feet.}$$

$$K = \frac{2\pi L}{33{,}000} = \frac{2 \times 3.1416 \times L}{33{,}000} = \frac{6.283L}{33{,}000}$$

$$\text{B.hp.} = \frac{6.283}{33{,}000} \times \text{r.p.m.} \times W$$

From this formula the brake horsepower can very readily be computed.

In order to compare graphically and to show just what the engine is actually doing, it will be necessary to plot the above readings in the form of curves, first between brake horsepower and revolutions per minute, and then between pounds of fuel and per brake horsepower per hour. This can be done in the manner shown in Fig. 522. With the data heretofore computed, plot curves with the brake horsepower as ordinates on the left, pounds of gasoline per brake horsepower per hour on the right and revolutions per minute, as abscissæ, as in Fig. 522.

These curves show that from the starting of the engine until the first few revolutions per minute, the rate of burning greatly exceeds the moving speed of the piston. The charge weight is good, the inertia of the gases is small, the volumetric efficiency is high and the inertia of parts is low.

Therefore, the horsepower climbs fast in relation to the revolutions per minute.

At other points above the fast-climbing range of power per revolutions per minute, the oil begins to lose a part of its viscosity and the inertia of the gases and parts becomes greater. These forces fairly balance with the greater efficiency of the fuel vaporization and the smoother application of power, consequently, for a certain period of increase in revolutions per minute, the increase of power is proportional.

At still a higher point in the increase of revolutions per minute, the expansion, due to the rapid increase in heat generation and hence the increase in friction, causes loss of rate of power generation. Decrease in the viscosity of the oil also aids in this loss of power. The comparative decrease in the rate of expansion, due to constant rate of burning, and

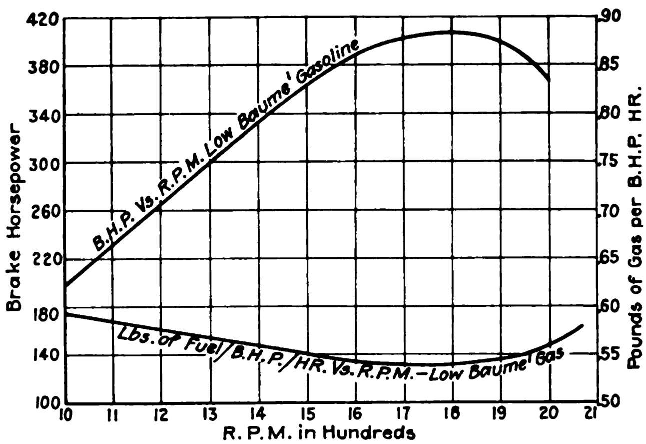

FIG. 522.—Effect of speed on B.hp. fuel consumption.

the decrease in the volumetric efficiency, heating of charge and insufficient time to take in charge causes less power application to the pistons. Due to these losses or causes, the rate of generation of power begins to fall off rapidly compared to the increase in the revolutions per minute, although the increase in power continues to a slight extent.

The *peak of the power*, as it is sometimes termed, is the point at which the forces, tending to slow down the increase of power output, in this case the mean effective pressure, begin to overbalance the forces, tending to increase the power, and the result is the falling off in mean effective pressure. It also results in the increase in the resistance forces and the decrease in power at speeds over the peak of the power speed.

Needle-valve Setting vs. B.hp. and Fuel Consumption. Another performance test to be run is the varying mixture quality test. Its purpose is to determine the effect of various needle-valve settings upon the overall performance and the fuel consumption of an engine at constant speed.

When the results of this test are plotted, the brake horsepower against needle-valve setting, and the pounds of gasoline per brake horsepower hour against needle-valve setting, the true characteristics of the engine will be indicated.

The engine to be tested is operated in a manner similar to the one just described in the previous performance test with a few exceptions. Start the engine, warm it up, time it and make necessary adjustments. Assign the men to their respective stations for the purpose of observing, operating, taking and recording readings of the needle valve setting, time, revolutions per minute, brake load, weight of fuel consumed, and tem-

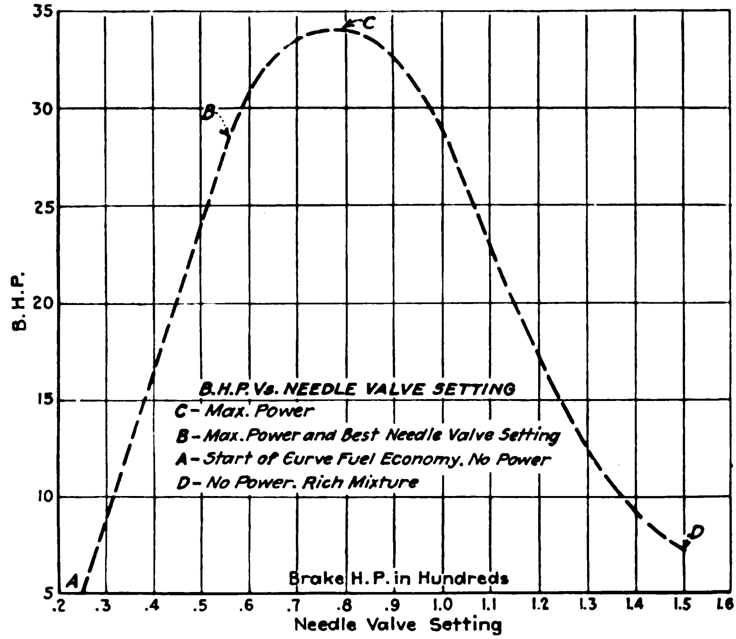

FIG. 523.—Effect of needle-valve setting on B.hp. (see sketch).

perature of cooling water, inlet and outlet. Before proceeding with this test, first examine the needle valve, which is of a special design. This needle valve fits into the main jet of the carburetor, which has been machined out larger and is provided with a seat to accommodate the needle valve. This needle valve is equipped with a large disk head which is calibrated in hundredths, one complete turn representing one, and any fraction of a turn a certain percentage of one. An indicator is provided with this disk, which registers any percentage of a turn of the needle valve for the required settings for the test.

With the throttle wide open and the spark fully advanced, proceed as follows: Set the needle valve for a quarter turn opening, which will give a lean mixture. Adjust the dynamometer load until the speed

registers 800 r.p.m. With this setting, make a 10-min. run and take readings every 2 min. during the entire run. The average of these readings for each operation, as outlined in previous paragraphs, is to be recorded in a log, similar to that shown in Fig. 523.

Again, the needle-valve setting is changed to read 50 per cent. or one-half a turn, which will give a richer mixture. Consequently the engine will tend to speed up. This will necessitate changing the dynamometer load to retain the speed of 800 r.p.m.

Repeat these operations for needle-valve settings at .75, 1, 1.25 and 1.50, or until the engine ceases to function. Keep the speed constant at 800 r.p.m. at all times by adjusting the load on the dynamometer.

A very accurate and complete record must be kept of each operation and the data recorded. The brake horsepower and the hourly consumption of the fuel per brake horsepower have to be computed from the data obtained by the test before they can be recorded in the log. Compute them as follows: Multiply the weight of fuel for 10 min. by 6 to obtain the weight of fuel consumed per hour. Divide the weight of fuel per hour by the brake horsepower and the result will be the weight of fuel per brake horsepower per hour. In solving for the brake horsepower proceed as follows:

$$\text{B.h.p.} = \text{K} \times \text{r.p.m.} \times \text{W}$$

where, B.hp. = Brake horsepower.
K = Constant.

R.p.m. = Revolutions per minute.
W = Brake load or weight.
L = Length of brake arm in feet.

$$\text{K} = \frac{2\pi \text{L}}{33{,}000} = \frac{2 \times 3.1416\text{L}}{33{,}000} = \frac{6.283\text{L}}{33{,}000}$$

$$\text{Therefore, B.hp.} = \frac{6.283\text{L}}{33{,}000} \times \text{r.p.m.} \times \text{W}$$

When all of the desired data has been tabulated, determine the true characteristics of the engine by plotting curves between the brake horsepower as ordinates and needle-valve setting as abscissæ; and between needle-valve setting as abscissæ and pounds of fuel per brake horsepower hour as ordinates. For this work use cross-section paper and make a layout like the one shown in Fig. 524. With the data obtained and recorded in the log, proceed to plot the curves between the brake horsepower and needle-valve setting as shown in Fig. 524. Then, on the same cross-section sheet, plot a curve between pounds of fuel per brake horsepower hour and needle-valve setting as shown in Fig. 525.

The reason for plotting these curves on the same cross-section proper is to bring out more clearly the most important and closely related points

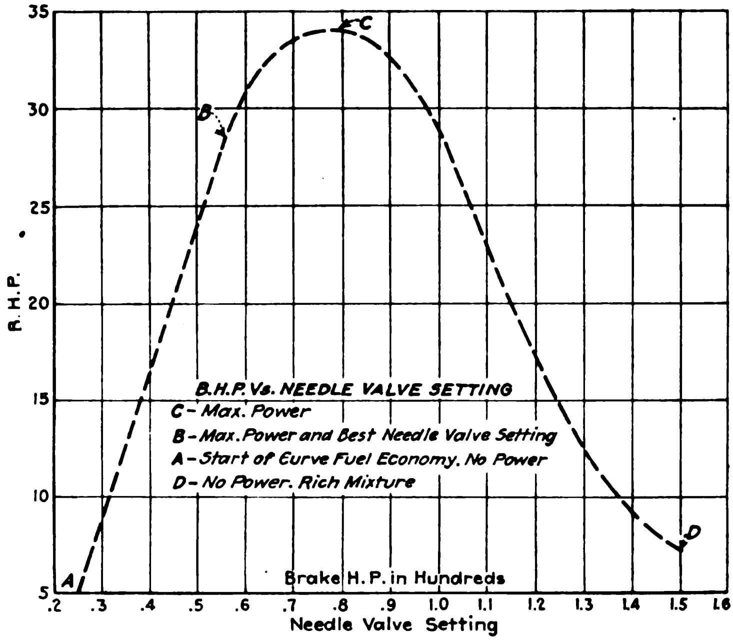

FIG. 524—Effect of needle-valve setting upon brake horsepower.

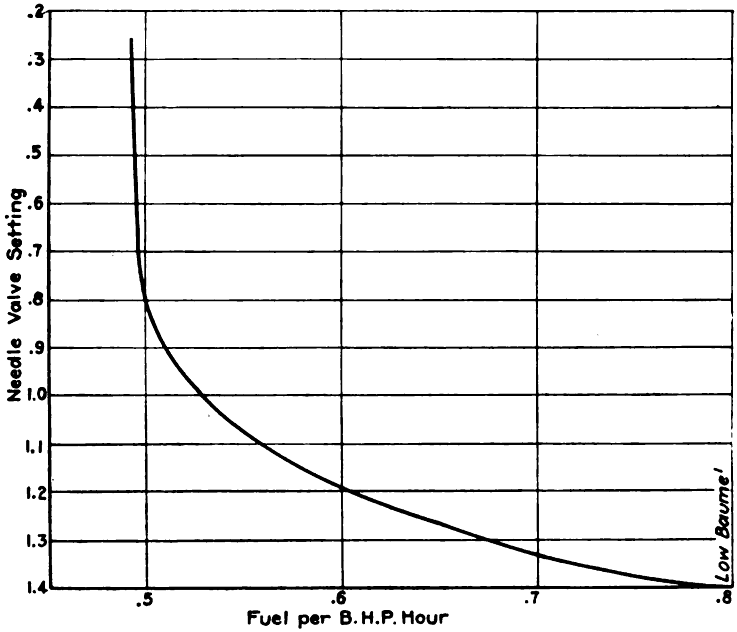

FIG. 525.—Effect of needle-valve setting upon fuel consumption per brake horsepower hour.

of the curves such as maximum power and economy. In Fig. 524, the curve of horsepower against needle-valve setting, the horsepower rises to a maximum at *C* and then falls off as the mixture gets richer, until the engine fails to run evenly, D. The curve of gas consumption should drop a little as the needle valve is opened, and then start to rise, continuing at an increasing rate up to the point where the engine fails to function properly. The comparison of the two curves, as shown in Fig. 523, shows that the point of maximum power does not occur at the same needle-valve setting as the point of maximum economy, but at a richer setting. These two points, one of maximum economy and the other of maximum power, show the range of running positions, between which it is correct to

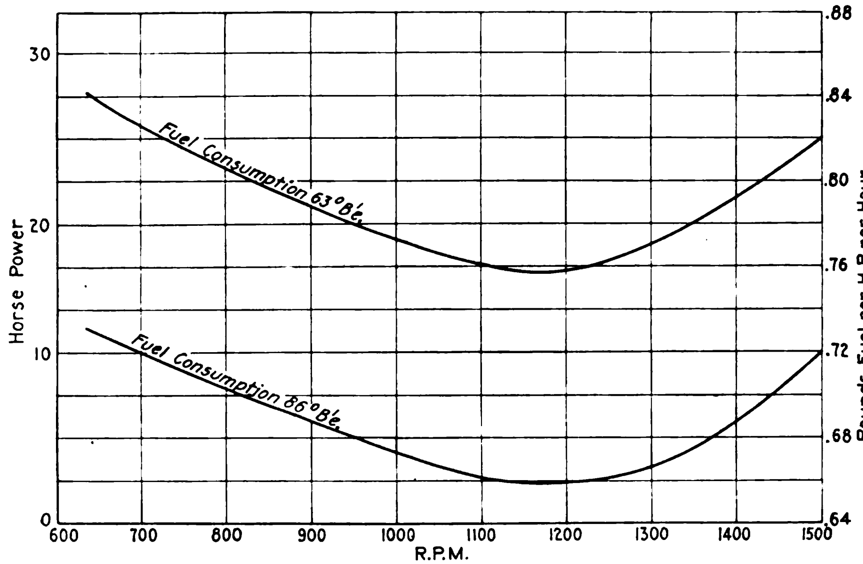

FIG. 526.—Horsepower vs. fuel consumption at full throttle; with varying speeds.

set the needle valve. At the maximum economy end of the range is the one to be used when a slight amount of power can be sacrificed in order to get economy of operation, as in a bombing plane or Blimp. With these machines, the weight of gasoline required to make a trip is a considerable item in the total weight, so economy of operation is essential.

The maximum power point is the one to be used in the case of *combat* planes which stay in the air for a short time only, but must have the greatest possible power from their engine. Therefore, the point of maximum power and maximum economy cannot be obtained at one needle-valve setting.

288. Run With High-Baumé Gasoline. In this test, run with high Baumé gasoline and follow the same procedure as outlined under "Performance Test." Record all data obtained in the logs as shown in Figs. 526, 527.

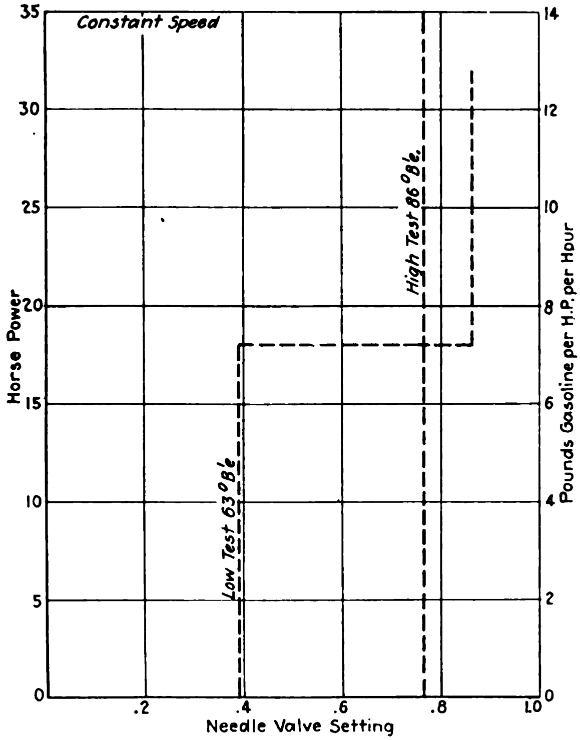

FIG. 527.—Horsepower vs. fuel consumption vs. needle valve setting; at constant speed.

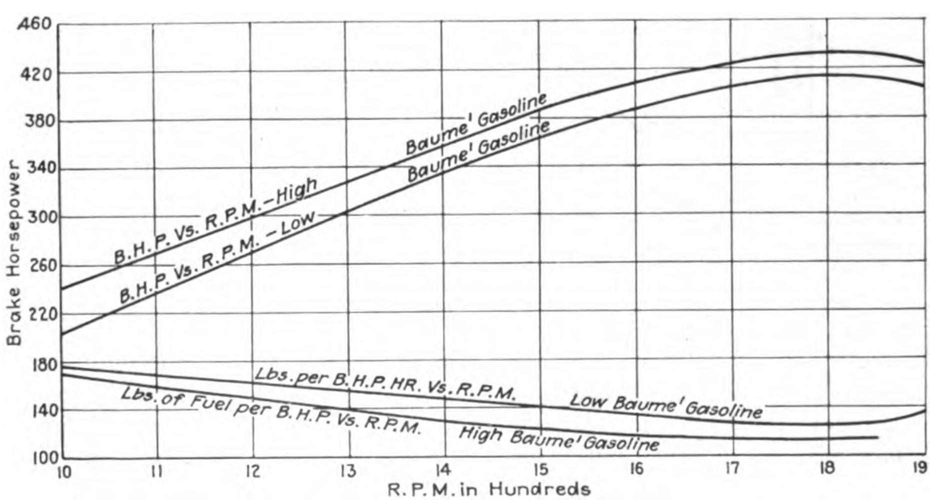

FIG. 529.—Comparison curves showing the effect of speed upon brake horsepower and fuel consumption per brake horsepower hour for high and low-Baumé gasoline.

When these readings are recorded and all computations made, plot the results on the same cross-section paper with the curves shown in Figs. 522 and 525. Such curves are shown in Figs. 529 and 530, and from these curves there may be obtained a good comparison of the character and performance of the engine when different grades of fuel are used.

In comparing these several curves, shown in Figs. 529 and 530, it will be noticed that the results obtained from the two grades of gasoline are almost the same, varying only in the range of operation. The high-Baumé gasoline operates with a leaner mixture, because of better vapori-

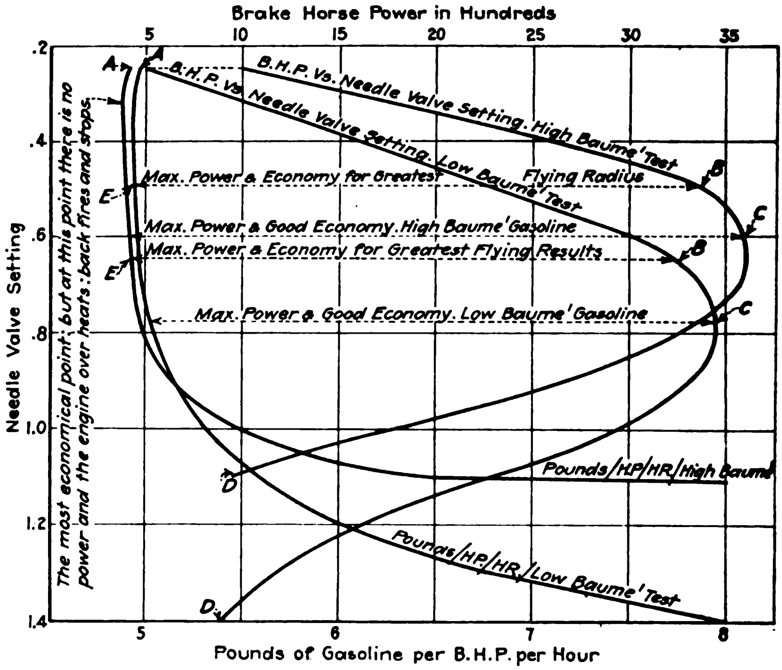

Fig. 530.—Comparison curves showing the effect of needle-valve setting upon brake horsepower and fuel consumption per brake horsepower-hour for high and low-Baumé gasoline.

zation, and also detonates more readily. The high-Baumé fuel has a higher rate of flow due to its low viscosity. The effect of this lesser viscosity is that it allows a greater amount of gas to flow through the valve for any given setting. It will also be noticed that the exhaust manifold heats up when running with lean mixtures. This is due to the fact that the mixture burns more slowly and is still burning when it passes into the manifold.

The practical range of needle-valve setting, the range between greatest economy and maximum power, is larger when using low-Baumé gasoline than when using high-Baumé. Experiment has proven that maximum

power is produced by a mixture of 1 part gasoline and 12 parts air, but that a mixture of about 1 to 15 will burn more completely, though slower. For this reason the power peak C, Fig. 530, on the power curve, and the greatest economy point on the needle-valve-setting curve, plotted identically, do not fall at the same point.

When the prime essential is flying radius, the engine should be run with the needle set at the point of greatest economy which is that point at which the engine will run without missing, overheating or overstressing. On the curves, Fig. 530, these points are represented by E for the low and high-Baumé respectively. When the prime essential is speed, with no regard for fuel economy or flying radius, the engine should be run with the needle valve set at the point of greatest power represented by C for the low and high-Baumé.

It will be noticed on the curves, Fig. 529, that more gasoline per b.hp.-hr. is used when running with low-Baumé gas. The reason for this is evident, for as shown by the curves, the engine will run with the needle valve open $1\frac{1}{2}$ turns when burning low-Baumé gasoline, while the greatest opening when using high-Baumé gasoline is only about $1\frac{1}{10}$ turns. At this point, the engine will choke and will labor more than when the needle valve is open $1\frac{1}{2}$ turns using low-Baumé fuel.

High-Baumé gasoline should be used in airplane engines because weight is an important factor. However, no matter what fuel is being used, the mechanic must be thoroughly familiar with the needle-valve settings or jet sizes of the carburetor on engines under his supervision. He also must adjust the carburetor according to the kind of work required of the engines.

Determining Mechanical Efficiency. The method of obtaining the brake horsepower, or the output of the engine, has been previously treated. A most important problem, the mechanical efficiency of the engine, will now be considered. Mechanical efficiency is the ratio of the brake horsepower to the indicated horsepower. If the mechanical losses, or the friction horsepower, were known, it would be a simple matter to obtain the indicated horsepower, for the indicated horsepower is the sum of the brake horsepower and the friction horsepower, which is expressed in the following formula:

$$\text{I.hp.} = \text{B.hp.} + \text{F.hp.}$$

Transforming the equation for mechanical efficiency we get the equation:

$$\text{Mechanical efficiency} = \frac{\text{B.hp.}}{\text{I.hp.}}$$

However, before proceeding with this test, we must take into consideration the fact that the mechanical losses are not constant for all speeds. If they were constant, the mechanical efficiency would also be

constant, but tests prove that the mechanical losses increase with speed. Therefore, the mechanical efficiency decreases with speed. In good gas engines mechanical efficiency varies from 85 to 90 per cent. In other engines it may run as low as 70 per cent. Mechanical efficiency depends upon design and the size of the bore.

To obtain the mechanical losses, the engine is first operated as explained in the performance tests. As soon as the engine has thoroughly warmed up, the instructor in charge will see that the men are at their respective stations; then start the run and proceed as follows:

With wide-open throttle and spark fully advanced, adjust the carburetor for the best possible setting. When this is done, cut in sufficient resistance to bring the speed down to 800 r.p.m. and maintain this speed throughout the run. It would be well to note here that we are adopting 800 r.p.m. for this run, not as the most efficient speed, but because it is a non-critical speed.

To obtain the true mechanical efficiency of any high-speed engine, it would be necessary to make a test run for each speed, plotting a curve for the mechanical efficiency of the different speeds.

With the engine tuned up properly and the speed registering 800 r.p.m., take readings for computing the brake horsepower as described in previous paragraphs, and record these readings in the log shown in Fig. 531 in the spaces labeled *with no cylinders cut out.*

To measure the drop in horsepower across each cylinder, start with cylinder No. 1L and remove the high-tension terminal leads. This will immediately cut out this cylinder from furnishing any power. The speed will immediately drop, due to the fact that seven cylinders are now carrying the load that was formerly carried by eight. Now, cut out sufficient resistance to bring the speed up to 800 r.p.m. and measure the drop in horsepower. Record the speed and brake load. Repeat this operation for each consecutive cylinder. Accuracy in taking readings and tabulating results in the log are very necessary in this test.

When the entire run has been completed and readings recorded for each run with one cylinder cut out, compute the mechanical efficiency. As the brake horsepower of eight cylinders equals the indicated horsepower of eight cylinders, minus the mechanical losses of eight cylinders, so, the brake horsepower of seven cylinders equal the indicated horsepower of seven cylinders, minus the mechanical losses of eight cylinders. This is due to the fact that when one cylinder is cut out the other seven must carry the mechanical losses, or friction horsepower, of all eight cylinders. From this information we derive the ensuing formulae by which can be computed the brake horsepower, the indicated horsepower and the mechanical efficiency of the engine. In these formulae, for convenience, use friction horsepower "F.hp."

$$\text{Mechanical Efficiency} = \frac{\text{B.hp.}}{\text{I.hp.}}$$

$$\text{B.hp.} = K \times \text{r.p.m.} \times W$$

$$K = \frac{2\pi}{33000} = \frac{2 \times 3.1416}{33000} = \frac{6.283}{33000}$$

$$\text{B.hp.} = \frac{6.283}{33000} \times \text{r.p.m.} \times W$$

$$\text{I.hp. of 1 cyl.} = \text{B.hp. of 8 cyl.} - \text{B.hp. of 7 cyl.}$$

$$\text{Mechanical Efficiency} = \frac{\text{B.hp. of 8 cyl.}}{\text{I.hp. of 8 cyl.}}$$

$$\text{Mechanical Efficiency} = \frac{\text{B.hp. of 1 cyl.} + \text{B.hp. of 2 cyl.} + \ldots \text{B.hp. of 8 cyl.}}{\text{I.hp. of 1 cyl.} + \text{I.hp. of 2 cyl.} + \ldots \text{I.hp. of 8 cyl.}}$$

This test run, which is performed to determine the indicated horsepower and mechanical efficiency of the engine, will also show the power distribution. However the results, or indicated horsepower, which will be obtained for the various cylinders, will not differ sufficiently to show any radical defect in the distribution of the mixture. The test shows the indicated horsepower of each cylinder, because when the spark is removed the only change that takes place is the removal of power from the cylinder. The mechanical losses are still there, the difference of the total power and the power with the cylinder not firing being indicated horsepower of the cylinder.

PART THREE

AIR STATION INSPECTION

CHAPTER X

INSPECTION TRIP TO AIR STATION

Systematic Inspection

Note: The following course of procedure is written for the Naval Air Station at Bay Shore, L. I. This is a station for the training of student flyers.

289. Grounds and Hangars. The object of the trip is to examine in detail an operating air station. The students are first taken through the two main hangars.

The beach is examined, noting the handling of planes from the hangars to the water, means of starting the engine and details of care and maintenance on the beach and also the duties of each man of the beach crew.

290. Workshops. The woodworking shop, where all the wood repair work for the station is done, is next visited. The work done in this shop includes repairs to propellers, boat hulls, pontoons, wing sections and all necessary carpenter work for the station.

The fabric shop adjoins the wood shop, where the wing fabric used in making wing repairs is cut and sewed, the wings covered, doped and painted. All spare wings are kept ready for use and stored in the storage space.

In the machine shop the engines are overhauled, cleaned, adjusted, necessary repairs made and the engines reassembled. Valve timing is checked and corrected, where necessary, magnetos timed and synchronized and the engines put in perfect mechanical condition. Here, also, all the machine parts for the station are made. The students examine all the machine tools in this shop, noting whether the machine is adapted for the work it performs or if some other machine would be more advantageous.

The work done in the sheet-metal shop includes all the copper work for the station consisting mostly in retipping propellers, all sheet-metal work and in addition oxy-acetylene and electric welding. Adjoining this shop is a carburetor and magneto room, where all repairs to both carburetors and magnetos are made. This is the only department on

the station authorized to repair magnetos and carburetors. All spare carburetors and magnetos are stored in this room and kept ready to be installed on engines.

291. Test Sheds. The test stands are next examined. There are two stands where the engines are tested after being overhauled. Engines are run from one-half to three hours, depending on their condition. During the test, water temperature and engine speed are noted.

292. Storerooms. The storeroom contains all spare engines, all surveyed engines and engines awaiting survey. The engine logs are kept in this room and also a checking system for determining the locations of the engines. Every engine has a brass check corresponding to its serial number. A board with a number of nails in it, each nail being marked with a plane number, test stand number, machine shop designation or storage number, is set up in the storage rooms. By hanging the checks on the correct nail the Officer-in-Charge is able to tell at any time exactly in what plane an engine is placed or if it is being repaired, tested or stored.

Study of Planes, Controls and Engine Mounting

293. Detail Examination. The students are taken back to the main hangars where the flying boats of the HS-IL and HS-2L type are located. The boats are examined in detail as to installation of engine, noting methods of fastening engine to plane, material of engine bed and methods of bracing. The instruments are examined with reference to kind, for what purpose used, location and ease of reading. These instruments include tachometer, ammeter, oil and water pressure gauges, oil and water thermometers, altimeter, inclinometer, air-speed meter, compass and clock. All radio apparatus, bomb-dropping devices and any other attachments are examined to determine the details of construction and method of operation. Special attention is given to the details of the system used for the controls.

The smaller hangars are next visited where are stored the F boats and seaplanes of the Aeromarine and Curtiss type. These are examined in detail as are the larger boats.

The following questions are given to the class making the trip and each man is assigned two or three questions on which he makes a written report. To find the answers, it is necessary for the man to get more detailed information than was possible in the regular inspection. Sufficient time is allowed each man in the class to obtain this detailed information from specialists in the particular subjects.

Questions

1. Object of station (patrol, instruction, etc.).
2. General inspection of air station grounds and buildings.

3. Engineering organization at station; maintenance, operation and general administration.

4. What types of engines are used?

5. What other types of engines have been used?

6. What troubles have been experienced with the Liberty engine?

7. What troubles on the other engines?

8. How long is an engine run before being overhauled?

9. Is a maintenance log kept to determine how often the various adjustments must be made and to give an idea as to the life of the various parts of the engine?

10. Are the various parts of the engine replaced according to the records of the operating log or are they allowed to remain on the engine until they wear out?

11. What is the life of spark plugs? What plugs are used?

12. What is the oil consumption of engines?

13. What method is used to get gasoline to the carburetor?

14. Has ignition been a source of trouble? If so, mention details.

15. What block test is given each engine after it has been overhauled?

16. What lubricating oil is used?

17. How often is the oil drained from the engines?

18. Is the oil reclaimed? Description of reclaiming apparatus.

19. What examination is given the engine and plane before a flight?

20. What examination is given on return from flight?

21. What method is employed for starting the engine?

22. Note system of storing spare engines and spare parts.

23. Note methods of handling engines in shop, on trucks and overhead trolley.

24. What machine tool equipment has the shop?

25. How is the power for the station generated?

26. Note type and size of radiators used on planes. How frequently must radiator water be replenished?

27. What auxiliary radiators are used?

28. What fire protection is provided on each plane?

29. What tools are carried on flight?

30. What types of seaplanes are used? Give general description, speed, type of pontoons, type of boat body, whether tractor or pusher, passenger capacity, number of engines.

31. Note type of propeller and number of blades.

32. Note type and location of machine gun.

33. Note type and location of radio apparatus, including generator, or other signalling devices.

34. Note number and size of bombs carried, also methods of holding and releasing.

35. Note types of bombsights.

36. How is the length of flight determined?

37. What instruments are used on the plane?

38. Note method of handling seaplanes from hangar to beach.

39. Mention any other facts learned, or observed on the station.